SR 99: ALASKAN WAY VIADUCT & SEAWALL REPLACEMENT PROGRAM

Noise and Vibration Technical Memorandum

S. Holgate Street to S. King Street Viaduct Replacement Project

Environmental Assessment

June 2008

TABLE OF CONTENTS

LIST OF EXHIBITS

ACRONYMS

μPa	micropascals
ANSI	American National Standards Institute
CFR	Code of Federal Regulations
City	City of Seattle
dB	decibels
dBA	A-weighted decibels
EIS	Environmental Impact Statement
EPA	United States Environmental Protection Agency
FHWA	Federal Highway Administration
FR	Federal Register
FTA	Federal Transit Administration
Hz	hertz (cycles per second)
ISO	International Organization for Standardization
L_{dn}	day/night sound level
L_{eq}	equivalent sound level
$L_{eq}(h)$	hourly equivalent sound level
L_{max}	maximum sound level
Pa	pascals
PPV	peak particle velocity
Project	SR 99: S. Holgate Street to S. King Street Viaduct Replacement Project
rms	root mean square
SMC	Seattle Municipal Code
SR	State Route
TNM	Traffic Noise Model
VdB	vibration decibels
WSDOT	Washington State Department of Transportation

Chapter 1 SUMMARY

This technical memorandum evaluates noise and vibration effects in areas likely to be affected by changes in traffic with the SR 99: S. Holgate Street to S. King Street Viaduct Replacement Project (the Project) and areas likely to be affected by construction noise or vibration. The study area extends approximately 500 feet on each side of State Route (SR) 99 from the vicinity of S. Holgate to S. King Streets.

Environmental noise is composed of many frequencies, each occurring simultaneously at its own sound pressure level. A common descriptor for environmental noise is the equivalent sound level (L_{eq}), a sound-energy average reported in A-weighted decibels (dBA) to account for how the human ear responds to sound frequencies. To the human ear, a 5-dBA change in noise is readily noticeable. A 10-dBA decrease would sound like the noise level has been cut in half.

Analysis of noise effects in the study area compares predicted future (year 2030) noise levels with existing levels and applicable criteria. Traffic noise levels are predicted at specific noise-sensitive locations (receptors) using the Federal Highway Administration (FHWA) Traffic Noise Model (TNM) in accordance with 23 CFR 772 and Washington State Department of Transportation (WSDOT) policy. Construction noise effects are described based on anticipated construction activities and typical noise levels for construction equipment.

Vibration is an oscillatory motion, which can be described in terms of displacement, velocity, or acceleration. Vibration effects related to annoyance and the potential for structural damage are evaluated for construction activities.

1.1 Affected Environment

The Project is located in a mostly industrial area interspersed with commercial, retail, and residential uses. Environmental noise from both transportation and other sources is typical of this environment.

Noise-sensitive land uses are concentrated along First Avenue S. between Railroad Way S. and S. King Street. To evaluate traffic noise effects, six sites, representing approximately 235 current and planned residential units, 32 artist lofts, 209 hotel rooms, a shelter, and two outdoor dining areas, were modeled using TNM. Traffic noise levels currently approach or exceed the exterior FHWA noise abatement criterion of 67 dBA for the 235 residential units and two outdoor dining areas.

1.2 Operational Effects and Mitigation

Without the Project, the peak traffic noise levels in 2030 are expected to increase by 1 to 2 dBA. With the Project, noise levels in some areas would decrease by as much as 2 dBA and increase in other areas by up to 1 dBA. Traffic noise effects in the study area occur as a result of high traffic volumes on the urban arterial grid. Mitigation of traffic noise levels is not feasible in this area because the majority of the traffic noise is generated by arterial traffic on the city street grid.

No annoyance effects from vibrations would occur inside buildings during operation of the Project.

1.3 Construction Effects and Mitigation

Construction may occur up to 24 hours per day, 7 days per week at times during the construction period, but would typically take place 5 days per week, 10 hours per day. Some night or weekend work may be required for roadway crossings, tail track relocation, or other critical construction phases. Nighttime work would be completed under temporary noise variances from the City of Seattle Department of Planning and Development. The Project would apply for temporary nighttime noise variances from the City of Seattle prior to any nighttime work.

To reduce construction noise at nearby receptors, mitigation measures such as those described in Section 6.2 could be incorporated into construction plans, specifications, and variance requirements.

During viaduct demolition, buildings closer than 100 feet could potentially exceed the vibration damage risk criteria for extremely fragile buildings. The criteria for newer buildings would not be exceeded at 25 feet. For pile driving, buildings closer than 400 feet would exceed the damage risk criteria for extremely fragile buildings, while at 50 feet they would not exceed the criteria for newer buildings.

To reduce construction vibration effects, mitigation measures such as those described in Section 6.4 could be incorporated into construction plans and specifications.

Chapter 2 METHODOLOGY

2.1 Noise

Ambient noise levels were measured for 15-minute periods at four locations near the study area. The measurement locations are representative of other sensitive receptors near the Project. At these locations, 15-minute measurements were taken with a Larson Davis Model 820 sound level meter to estimate the hourly equivalent sound level or L_{eq}(h). The goal was to describe the existing noise environment, identify major noise sources in the study area, validate the noise model, and characterize the weekday background environmental noise levels.

The FHWA's Traffic Noise Model (TNM) Version 2.5 computer model (USDOT 2003) was used to predict L_{eq}(h) traffic noise levels. The TNM is used to obtain precise noise-level estimates at discrete points by considering interactions between different noise sources and the effects of topographical features on noise propagation. The model estimates the acoustic intensity at a receiver location, calculated from a series of straight-line roadway segments (USDOT 2005). Noise emissions from free-flowing traffic depend on the number of automobiles, medium trucks, and heavy trucks per hour; vehicular speed; and reference noise emission levels of an individual vehicle. TNM also considers the effects of intervening barriers, topography, trees, and atmospheric absorption.

DXF-format computer design files were exported from MicroStation and imported into TNM with major roadways, topographical features, building rows, and sensitive receptors digitized into the model. Elevations were added from the topographic contour data. Elevations for planned improvements were taken from design profiles. The noise model extended approximately 500 feet on each side of SR 99 from the vicinity of S. Holgate Street to S. King Street.

The TNM was validated by comparing the measured noise level with the model noise level, using the traffic counts at the time of the noise measurement. The measured and modeled noise levels were within 2 dBA, therefore the TNM is valid (Exhibit 2-1).

A building survey was conducted within 500 feet of proposed long-term improvements to determine the number of noise-sensitive receptors in the study area. The type of use, presence of balconies, and number of residential units or other sensitive uses in the buildings were collected for any buildings that housed sensitive uses (Activity Categories B and E, see Exhibit 3-6). These data were used to estimate the number of sensitive receptors represented by the modeled noise receptors and are included in Chapter 4, Affected Environment.

2.2 Vibration

Existing vibration levels were measured at one location near the existing viaduct using the following equipment:

- Larson Davis Model 2900 1/3 Octave Band Real-Time Analyzer
- PCB Model 393A03 ICP Accelerometer
- PCB Model 699A02 Handheld Shaker (Calibrator)

The vibration levels of different heavy trucks passing by were monitored to determine the maximum root mean square (rms) vibration velocity levels generated by these events. These measurements were used as a baseline for evaluation of the future potential for operational vibration effects.

The potential for construction vibration effects was estimated from prior measurements of construction equipment. The reference vibration data used for this analysis were taken from the available literature (see Chapter 8, References) and supplemented by measurements conducted on other construction projects. The data were used to establish a distance beyond which construction activities would not cause damage to sensitive structures in accordance with vibration guidelines and criteria as found in ISO Standard 2631 and ANSI Standard S3.29.

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Chapter 3 BACKGROUND, STUDIES, AND COORDINATION

3.1 Characteristics of Sound

Sound is created when objects vibrate, resulting in a minute variation in surrounding atmospheric pressure called sound pressure. The human ear's response to sound depends on the magnitude of a sound as a function of its frequency and time pattern (EPA 1974). Magnitude measures the physical sound energy in the air. The human ear detects variations in pressure as small as 20 micropascals (μPa [10^{-6} pascals]). Sound pressure greater than about 100 pascals (Pa) is painfully loud. This range of magnitude from the faintest to the loudest sound the ear can hear is so large that sound pressure levels are expressed on a logarithmic scale in units called decibels (dB) that quantify the energy contained in the sound pressure. A sound pressure of 20 μPa is defined as 0 dB (the threshold of hearing for a healthy ear), while a sound pressure of 100 Pa is about 130 dB (the approximate threshold for pain).

Because of the logarithmic decibel scale, a doubling of the number of noise sources, such as the number of cars operating on a roadway, increases noise levels by 3 dB. A tenfold increase in the number of noise sources will add 10 dB. As a result, a noise source emitting a noise level of 60 dB combined with another noise source of 60 dB yields a combined noise level of 63 dB, not 120 dB.

Loudness, compared to physical sound measurement, refers to how people subjectively judge a sound. This varies from person to person. The human ear can better perceive changes in sound levels than judge the absolute sound level. A 3-dB increase is barely perceptible, while a 5- or 6-dB increase is readily noticeable and sounds as if the noise is about one and one-half times as loud. A 10-dB increase appears to be a doubling in noise level to most listeners.

Humans also respond to a sound's frequency or pitch. The human ear can perceive sounds with a frequency between approximately 20 and 20,000 hertz (Hz), but it is most effective at perceiving sounds between approximately 1,000 and 5,000 Hz. Environmental sounds are composed of many frequencies, each occurring simultaneously at its own sound pressure level. Frequency weighting, which is applied electronically by a sound level meter, combines the overall sound frequency into one sound level that simulates how an average person hears sounds. The commonly used frequency weighting for environmental sounds is A-weighting (dBA), which is most similar to how humans perceive sounds of low to moderate magnitude.

Sound levels decrease as the distance increases from the sound source. For a line source, such as a roadway, sound levels decrease 3 dBA over hard ground (concrete or pavement) or 4.5 dBA over soft ground (grass) for every doubling of distance between the source and the receptor (the individual hearing the noise). For a point source, such as a piece of construction or ventilation equipment, sound levels decrease between 6 and 7.5 dBA for every doubling of distance from the source.

The propagation of sound can be greatly affected by terrain and the elevation of the receiver relative to the sound source. Level ground is the simplest case. Noise travels in a straight line-of-sight path between the source and the receiver. The addition of a berm or other area of high terrain reduces the sound energy arriving at the receiver. Breaking the line of sight between the receiver and the highest sound source results in a sound level reduction of approximately 5 dBA.

If the source is depressed or the receiver is elevated, sound generally will travel directly to the receiver. In some situations, sound levels may be reduced because the terrain crests between the source and the receiver, resulting in a partial sound barrier near the receiver. In the case of traffic noise, if the roadway is elevated or the receiver is depressed, noise may be reduced at the receiver because the edge of the roadway can act as a partial noise barrier, blocking some sound transmission between the source and the receiver. Exhibit 3-1 shows how the effectiveness of the shielding is a function of the additional length the noise must travel over the barrier compared to a straight path.

Sound may also be reflected from buildings and other solid structures. In certain cases when direct sound is blocked by a barrier or other shielding, the reflected sound may be greater than the sound arriving directly at the receiver, as pictured in Exhibit 3-2.

Noise levels from traffic sources depend on volume, speed, and the type of vehicle. Generally, an increase in volume, speed, or vehicle size increases traffic noise levels. Vehicular noise is a combination of noises from the engine, exhaust, and tires. Other conditions affecting traffic noise include defective mufflers, steep grades, terrain, vegetation, distance from the roadway, and shielding by barriers and buildings.

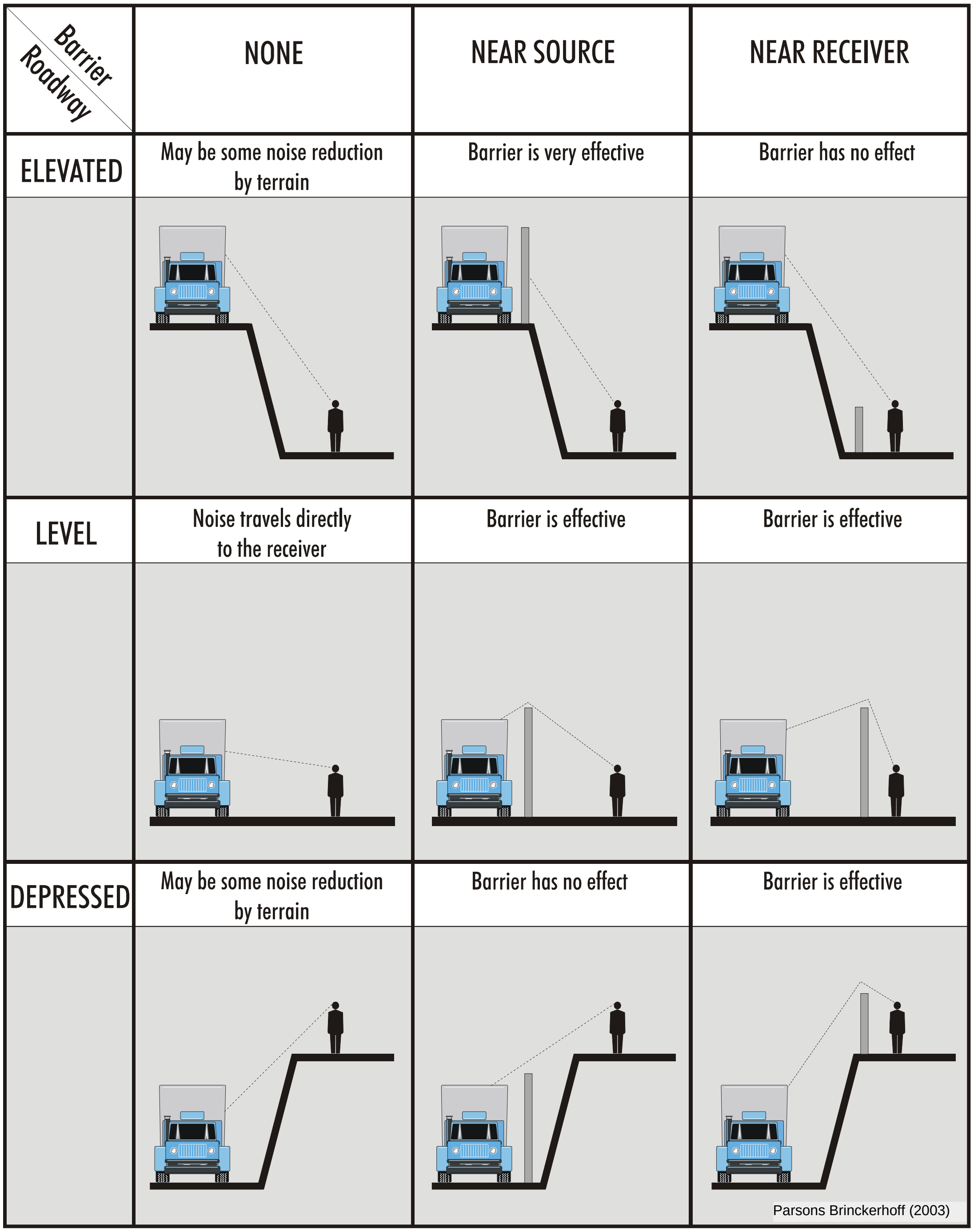


Exhibit 3-1. Effect of Terrain and Barriers on Sound Propagation

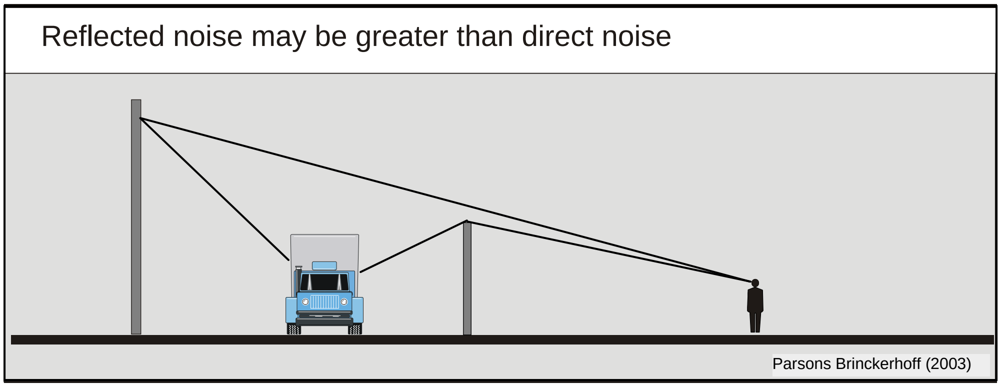


Exhibit 3-2. Effect of Reflected Sound

3.2 Sound Level Descriptors

A widely used descriptor for environmental noise is the equivalent sound level (L_{eq}). The L_{eq} is a measure of the average sound energy during a specified period of time. L_{eq} is defined as the constant level that, over a given period of time, transmits the same amount of acoustical energy to the receiver as the actual time-varying sound. Occasional high sound energy levels have more effect on L_{eq} than the general background sound energy level because the sound level (in dBA) represents sound energy logarithmically. Two sound patterns, one of which has a lower background level but a higher maximum level, can have the same L_{eq}, as shown in Exhibit 3-3.

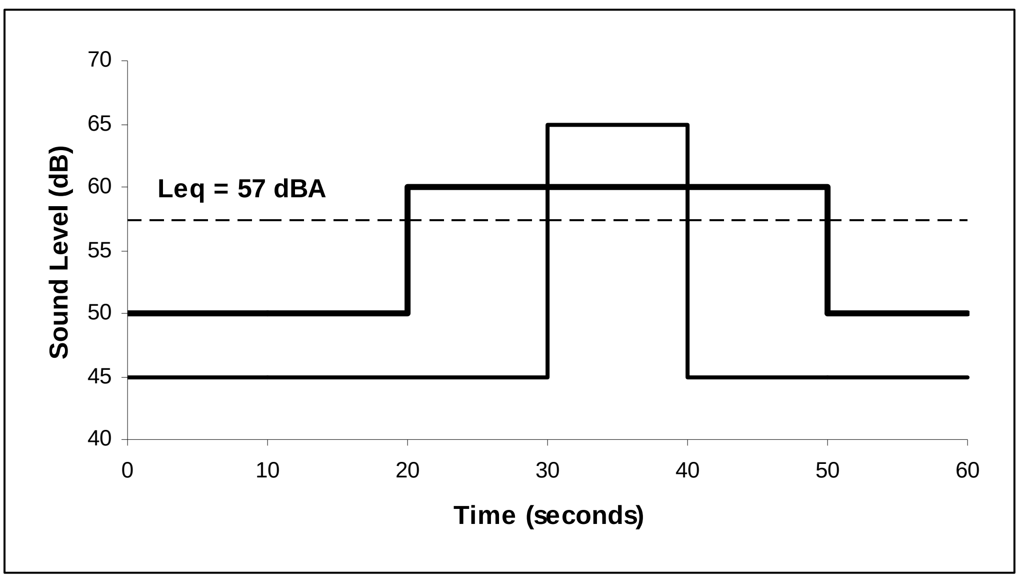


Exhibit 3-3. Example of Two Sound Patterns with the Same L_{eq}(1 minute)

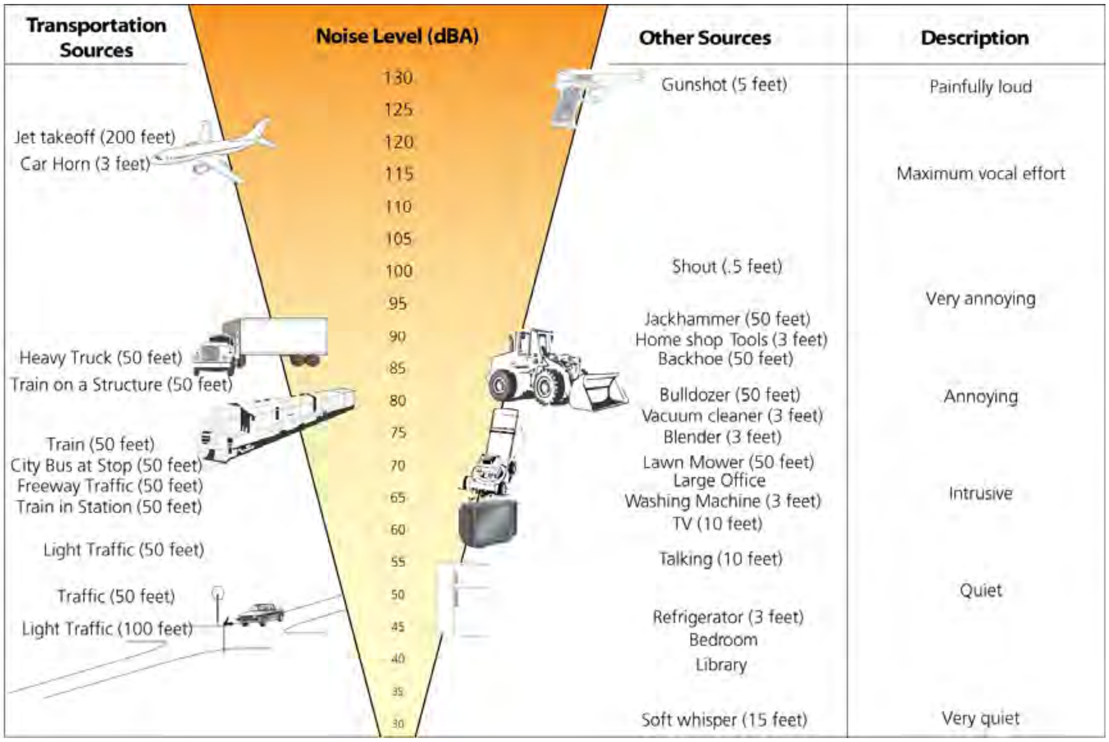
L_{eq} is reported for different measurement periods. L_{eq} measured over a 1-hour period is the hourly L_{eq} [L_{eq}(h)], which is often used to analyze highway noise effects and abatement. To analyze noise effects and abatement in residential areas, analysts use a daily averaged noise level that more heavily ranks noise that occurs at night. The day/night level (L_{dn}) adds 10 dBA to noise levels that occur between 10 p.m. and 7 a.m. to account for people's greater sensitivity to noise at night.

Short-term noise levels, such as those from a single truck passing by, can be described by either the total noise energy or the highest instantaneous noise level that occurs during the event. The sound exposure level (SEL) is a measure of total sound energy from an event, and it is useful in determining what the L_{eq} would be over a period in time when several noise events occur. The maximum sound level (L_{max}) is the loudest short-duration sound level that occurs during a single event. L_{max} is related to effects such as speech interference and sleep disruption. In comparison, L_{min} is the minimum sound level during a period of time.

People will often find a moderately high, constant sound level more tolerable than a quiet background level interrupted by frequent high-level noise intrusions. An individual's response to sound depends greatly upon the range in which the sound varies in a given environment. For example, steady traffic noise from a highway is normally less bothersome than occasional aircraft flyovers in a relatively quiet area. In light of this subjective response, it is often useful to look at a statistical distribution of sound levels over a given period in addition to the average sound level. A statistical distribution allows for a more thorough description of the range of sound levels during the given measurement period by identifying the sound level exceeded, as well as the percentage of time it was exceeded. These distributions are identified with an L_n where "n" is the percentage of time that the levels are exceeded. For example, the L_{10} level is the noise level that is exceeded 10 percent of the time.

3.3 Typical Sound Levels

Typical A-weighted sound levels from various sources are presented in Exhibit 3-4. The sound environments described, which range from a quiet whisper or light wind at 30 dBA to a jet takeoff at 120 dBA, demonstrate the great range of the human ear. A typical conversation is in the range of 60 to 70 dBA.



Sources: USDOT (1995); EPA (1971, 1974).

Exhibit 3-4. Typical Sound Levels

Background environmental sound levels vary widely in different environments. The United States Environmental Protection Agency (EPA) evaluated L_{dn} sound levels at various locations and has developed qualitative descriptions of the sound environments that experience various sound levels (Exhibit 3-5). The L_{dn} level is a measure of 24-hour environmental sounds and is often lower than the peak 1-hour L_{eq} sound levels that are evaluated in this report in accordance with FHWA and WSDOT procedures.

Exhibit 3-5. Typical Outdoor Sound Levels in Various Environments

Qualitative Description	L_{dn} (dBA)
City Noise (Downtown Major Metropolis)	80
	75
Very Noisy Urban	70
Noisy Urban	65
Urban	60
Suburban	55
Small Town and Quiet Suburban	50
	45

Source: EPA (1974).

3.4 Effects of Noise

Environmental noise at high intensities directly affects human health by causing hearing loss. Although scientific evidence currently is not conclusive, noise is suspected of causing or aggravating other diseases. Environmental noise indirectly affects human welfare by interfering with sleep, thought, and conversation. The FHWA noise abatement criteria are based on speech interference, which is a well documented effect that is relatively reproducible in human response studies.

3.5 Noise Regulations and Effect Criteria

3.5.1 Traffic Noise Criteria

Applicable noise regulations and guidelines provide a basis for evaluating potential noise effects. For federally funded highway projects, traffic noise effects occur when predicted L_{eq}(h) noise levels approach or exceed FHWA's established noise abatement criteria or substantially exceed existing noise levels (USDOT 1982; Noise Abatement Council). WSDOT noise policy adopts the FHWA criteria (WSDOT 2007). Although "substantially exceed" is not defined in FHWA criteria, WSDOT considers an increase of 10 dBA or more to be a substantial increase.

The FHWA noise abatement criteria specify exterior L_{eq}(h) noise levels for various land activity categories (Exhibit 3-6). The noise criterion is 57 dBA for receptors where serenity and quiet are of extraordinary significance (Category A). The noise criterion is 67 dBA for residences, parks, schools, churches, and similar areas (Category B), and the noise criterion is 72 dBA for developed lands (Category C). WSDOT considers a noise effect to occur if predicted L_{eq}(h) noise levels approach within 1 dBA of the noise abatement criteria in Exhibit 3-6. Thus, if a noise level were 66 dBA or higher, it would approach or exceed the FHWA noise abatement criterion of 67 dBA for residences.

WSDOT defines severe noise effects as traffic noise levels that exceed 80 dBA outdoors in Category B areas. Severe noise effects also occur if predicted future noise levels exceed existing levels by 30 dBA or more in noise-sensitive locations as the result of a project. Traffic noise levels between 76 and 79 dBA outdoors in Category B areas are considered substantial.

by 10 dBA for 5 minutes, or by 15 dBA for 1.5 minutes during any 1-hour period. These allowed exceptions are referred to in terms of the percentage of time a certain level is exceeded; an L_{25} is the noise level that is exceeded 15 minutes during an hour. Therefore, the permissible L_{25} would be 5 dBA greater than the values in Exhibit 3-7, provided that the noise level is below the permissible level in Exhibit 3-7 for the rest of the hour and never exceeds the permissible level by more than 5 dBA. An hourly L_{eq} of approximately 2 dBA higher than the values in Exhibit 3-7 is an equivalent sound level to the permissible levels, including the allowed short-term exceedances. Using this example, an L_{eq}(h) of 59 dBA approximately corresponds to a noise level of 57 dBA for 45 minutes and 62 dBA for 15 minutes, which is the maximum permissible noise level created by a source in a commercial zone and received by a property in a residential zone.

Construction activities between 7 a.m. and 10 p.m. on weekdays and between 9 a.m. and 10 p.m. on weekends are allowed to exceed the property line standards per the following limits, measured at 50 feet or the property line, whichever is farther (SMC 25.08.425):

1. Earth-moving or other large construction equipment may exceed the applicable property line limit by 25 dBA.
2. Portable powered equipment may exceed the limit by 20 dBA.
3. Impact equipment, such as jackhammers, may not exceed an L_{eq}(h) of 90 dBA or an L_{eq}(7.5 minutes) of 99 dBA. The use of impact equipment is also not allowed between the hours of 8 a.m. to 5 p.m. on weekdays and between 9 a.m. and 5 p.m. on weekends.

3.6 Characteristics of Vibration

Vibration is an oscillatory motion, which can be described in terms of displacement, velocity, or acceleration. There is no net movement of the vibrating element; however, vibrational energy does flow from element to element within a given medium. Displacement is the easiest descriptor to understand. For a vibrating floor, the displacement is simply the distance that a point on the floor moves away from its static position. The velocity represents the instantaneous speed of the floor movement, and acceleration is the rate of change of the speed. Although displacement is easier to understand than velocity or acceleration, it is rarely used for describing ground-borne vibration. This is because most transducers used for measuring ground-borne vibration use either velocity or acceleration and, more important, the response of humans, buildings, and equipment to vibration is more accurately described using velocity or acceleration.

3.7 Vibration Descriptors

One of the several different methods that are used to quantify vibration amplitude is peak particle velocity (PPV), which is defined as the maximum instantaneous positive or negative peak of the vibration signal. PPV is often used in monitoring of blasting vibration since it is related to the stresses that are experienced by buildings.

Although PPV is appropriate for evaluating the potential of building damage, it is not suitable for evaluating human response. It takes some time for the human body to respond to vibration signals. In a sense, the human body responds to average vibration amplitude. Because the net average of a vibration signal is zero, the root mean square (rms) amplitude is used to describe the "smoothed" vibration amplitude. The rms of a signal is the square root of the average of the squared amplitude of the signal. The average is typically calculated over a 1-second period. The rms amplitude is always less than the PPV and is always positive. The PPV and rms velocity are normally described in inches per second in the United States and meters per second in the rest of the world.

Although it is not universally accepted, decibel notation is in common use for vibration. Decibel notation compresses the range of numbers required to describe vibration. Vibration velocity level in decibels is defined as the following:

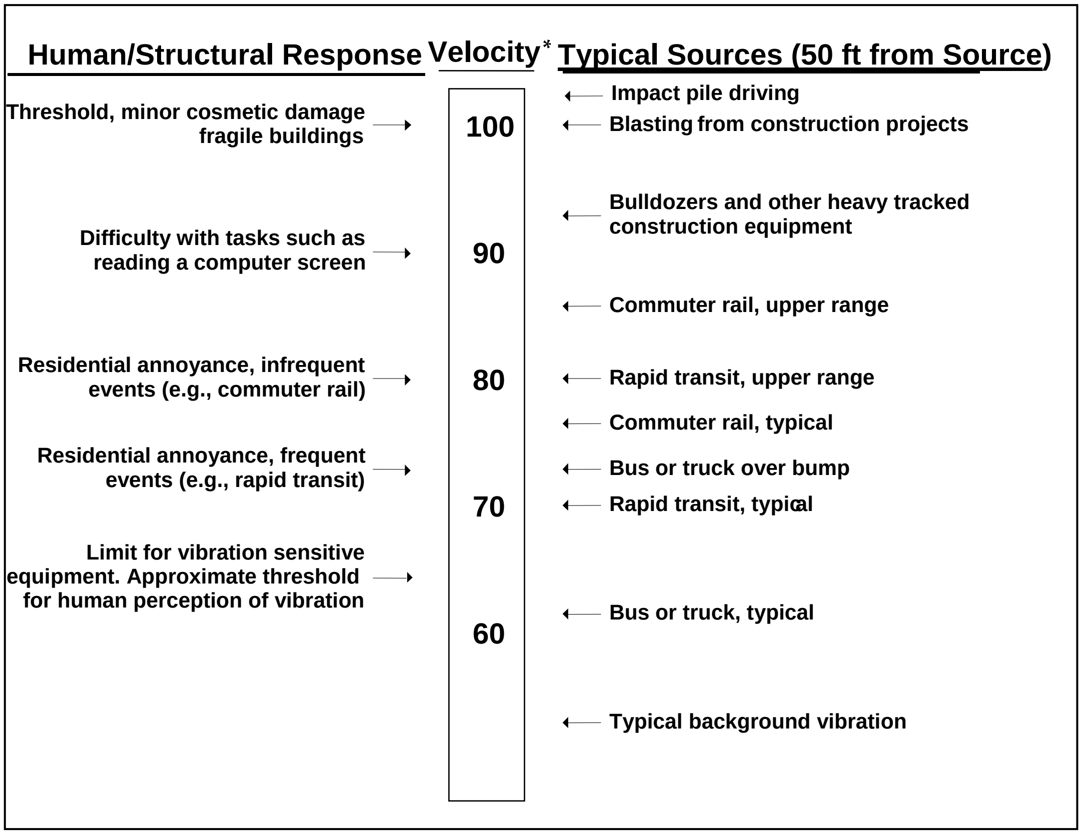
$$L_v = 20\log(V/V_{ref})$$

where "L_v" is the velocity level in decibels,
"V" is the rms velocity amplitude, and
"V_{ref}" is the reference velocity amplitude.

A reference must always be specified whenever a quantity is expressed in terms of decibels. All vibration levels in this report are referenced to $1\text{x}10^{-6}$ inches per second. Although not a universally accepted notation, the abbreviation VdB is used in this document to indicate vibration decibels to reduce the potential for confusion with sound decibels.

3.8 Typical Vibration Levels

In contrast to airborne noise, ground-borne vibration is not a phenomenon that most people experience every day. The background vibration velocity level in residential areas is usually 50 VdB or lower, well below the threshold of perception for humans, which is around 65 VdB (Exhibit 3-8). Most perceptible indoor vibration is caused by sources within buildings such as operation of mechanical equipment, movement of people, or slamming of doors. Typical outdoor sources of perceptible ground-borne vibration are construction equipment, steel-wheeled trains, and traffic on rough roads. Pile driving is one of the greatest common sources of vibration. The vibration from traffic is rarely perceptible if the roadway is smooth. The range of interest is from approximately 50 VdB to 100 VdB.



Note: *RMS vibration velocity level in VdB relative to 10^{-6} inches per second.
Source: USDOT (1995).

Exhibit 3-8. Common Vibration Sources and Levels

Background vibration is usually well below the threshold of human perception and is of concern only when the vibration affects very sensitive manufacturing or research equipment. Electron microscopes and high-resolution lithography equipment are typical of equipment that is moderately sensitive to vibration and may be disturbed by vibration levels greater than 65 VdB. Some highly sensitive equipment can be disturbed by vibration levels below 65 VdB. Defining the limits of equipment that is highly sensitive to vibration would require a review of the specific equipment. Although the perceptibility threshold is about 65 VdB, human response to vibration is not usually significant unless the vibration exceeds 70 VdB. This is a typical level 50 feet from a rapid transit or light rail system. Buses and trucks rarely create vibration that exceeds 70 VdB unless there are bumps in the road.

3.9 Effects of Vibration

Ground-borne vibration can be a concern for occupants of nearby buildings during construction activities associated with a proposed project. However, it is unusual for vibration from sources such as buses and trucks to be perceptible, even in locations close to major roads. The most common sources of ground-borne vibration are trains, buses on rough roads, and construction activities such as blasting, pile driving, and operating heavy earth-moving equipment.

The effects of ground-borne vibration include perceptible movement of the building floors, rattling of windows, shaking of items on shelves or hanging on walls, and rumbling sounds. In extreme cases, vibration can cause damage to buildings. Building damage is not a factor for normal transportation projects with the occasional exception of blasting, pile driving, and demolition of structures, which may occur during construction.

The rumbling sound caused by the vibration of room surfaces is called ground-borne noise. The annoyance potential of ground-borne noise is usually characterized with the A-weighted sound level. Although the A-weighted level is almost the only metric used to characterize community noise, there are potential problems with characterizing low-frequency noise using A-weighting. This is because of the non-linearity of human hearing, which causes sounds dominated by low-frequency components to seem louder than broadband sounds that have the same A-weighted level. The result is that ground-borne noise with a level of 40 dBA sounds louder than 40 dBA broadband noise. This is accounted for by setting the limits for ground-borne noise lower than for broadband noise.

3.10 Vibration Effect Criteria

Criteria for construction ground vibration must address both:

1. The potential for disturbance and annoyance to building occupants, and
2. The potential for damage to nearby buildings and other nearby structures.

Temporary vibration effects may occur in the local area during construction as a consequence of the use of blasting, pile drivers, jackhammers, hoe rams, soil compactors, and other heavy construction equipment. Buildings near the construction site respond to these vibrations with varying results, ranging from perceptible effects at the lowest levels, low rumbling sounds and noticeable vibrations at moderate levels, and slight damage at the highest levels. Ground vibrations from construction activities rarely reach the levels that can damage structures but can achieve moderate levels in buildings very close to a site. Impact pile drivers generally cause the highest vibration levels compared to other types of equipment.

The precise assessment of potential construction effects requires detailed information on the proposed construction methods, the specific construction activity, the types of construction equipment, the characteristics of underlying soils, and the existing conditions and use of nearby buildings. Measurement of existing vibration levels at sensitive sites also is required to determine the potential sensitivity of people living in the vicinity of the construction site.

3.10.1 Annoyance Criteria

Annoyance from construction vibration would depend on the magnitude of vibration as well as on the human activity involved. Vibration produced during construction operations becomes a concern when it can be felt. Determining acceptable vibration levels is often problematic because of its subjective nature with respect to being a nuisance. It is the unpredictability and unusual nature of a vibration source, rather than the level itself, that is likely to result in complaints. The effect of intrusion tends to be psychological rather than physiological, and it is more of a problem at night when occupants of buildings expect no unusual disturbance from external sources. Complaints may occur when vibration levels from an unusual source exceed the human threshold of perception (generally in the range of PPV 0.008 to 0.012 inch/second), even though these levels are much less than what would result from slamming a door in a modern masonry building. People's tolerance will be improved provided that the origin of the vibrations is known in advance and no damage results.

The criteria used in determining annoyance depend on the type of activities inside the building, as well as time of day. Conservative design criteria used for assessing human sensitivity during construction have been developed by the International Organization for Standardization (ISO) and the American National Standards Institute (ANSI). These criteria levels are shown in Exhibit 3-9.

3.10.2 Potential Building Damage Criteria

Building damage is the primary concern with regard to construction vibration. For this purpose, construction vibration is generally assessed in terms of PPV. The potential for cosmetic or structural damage due to construction activities is assessed on the basis of effect criteria developed by the Acoustical Society of America (2001), ISO (1989), and the Federal Transit Administration (FTA 2006).

Exhibit 3-9. Criteria for Annoyance Caused by Ground-borne Vibration

Building Use Category	Maximum Vibration Velocity (inches/second)	Comments
Hospital and critical areas	0.005	
Residential (nighttime)	0.007	
Residential (daytime)	0.01	Criterion also applies to churches, schools, hotels, and theaters
Office	0.02	Criterion applies to commercial establishments
Factory	0.03	Criterion applies to industrial establishments

Source: ISO Standard 2631 (1974) and ANSI Standard S3.29-2001.

3.10.3 Vibration Criteria to Prevent Structural Damage

Extensive studies conducted by the United States Bureau of Mines suggest that a peak vibration velocity of 2 inches per second should not be exceeded if major structural damage of buildings is to be prevented. Potential damage to underground and buried utilities could occur at vibration levels above 4.0 inches per second (Nicholls et al. 1971). Criteria for sustained construction vibrations, which are normally expected during construction, generally limit vibration velocities to 0.5 to 1.0 inch per second.

More comprehensive guidelines are provided in Swiss Standard SN 640312 and have been checked for conformance with similar vibration criteria established by the American Association of State Highway and Transportation Officials, United States Bureau of Mines, and other relevant standards. Exhibits 3-10 and 3-11 represent the structural categories and vibration criteria for use in selecting appropriate construction vibration limits.

Exhibit 3-10. Structural Categories According to SN 640312

Structural Category	Definition
I	Reinforced-concrete and steel structures (without plaster), such as industrial buildings, bridges, masts, retaining walls, unburied pipelines; underground structures such as caverns, tunnels, galleries, lined and unlined
II	Buildings with concrete floors and basement walls, above-grade walls of concrete, brick or ashlar masonry; ashlar retaining walls, buried pipelines; underground structures such as caverns, tunnels, galleries, with masonry lining
III	Buildings with concrete basement floors and walls, above-grade masonry walls, and timber joist floors
IV	Buildings that are particularly vulnerable or worth preserving

Exhibit 3-11. Acceptance Criteria of SN 640312

Structural Category	Continuous or Steady-State Vibration Sources[a]		Transient or Impact Vibration Sources[b]	
	Frequency (Hz)	Max Velocity (In/s)	Frequency (Hz)	Max Velocity (In/s)
I	10–30	0.5	10–60	1.2
	30–60	0.5–0.7	60–90	1.2–1.6
II	10–30	0.3	10–60	0.7
	30–60	0.3–0.5	60–90	0.7–1.0
III	10–30	0.2	10–60	0.5
	30–60	0.2–0.3	60–90	0.5–0.7
IV	10–30	0.12	10–60	0.3
	30–60	0.12–0.2	60–90	0.3–0.5

Hz = hertz; In/s = inches per second

[a] Continuous or steady-state vibration consists of equipment such as vibratory pile drivers, hydromills, large pumps and compressors, bull dozers, trucks, cranes, scrapers and other large machinery, jackhammers and reciprocating pavement breakers, and compactors.

[b] Transient or impact vibration consists of activities such as blasting with explosives, drop chisels for rock breaking, buckets, impact pile drivers, wrecking balls and building demolition, gravity drop ground compactors, and pavement breakers.

The FTA guidance on vibration damage threshold covers “fragile buildings” (0.20 inch/second PPV) and “extremely fragile historic buildings” (0.12 inch/second PPV), which relate to Building Category IV of the Swiss Standard for buildings of “particularly high sensitivity.” The majority of buildings along the proposed alignment for this Project are non-fragile and fall under Building Categories II or III, indicating they have low to average sensitivity to vibration.

3.10.4 Vibration Criteria Adopted for this Project

The criteria used in determining annoyance inside buildings are shown in Exhibit 3-9.

Although FHWA, WSDOT, and the City of Seattle do not have specific vibration effect criteria, to prevent structural damage, a vibration effect criterion of 0.12 inch/second PPV has been adopted for extremely fragile structures and 0.50 inch/second for all other occupied buildings. These criteria are consistent with FTA criteria and are protective of potentially fragile historic structures. Structures in the study area that may be extremely fragile include unrestored areaways, the spaces beneath the sidewalks of older buildings, and historic buildings that have not been structurally retrofitted. The damage criterion for underground buried structures is a PPV of 4.0 inches/second. Older cast-iron water mains may be more sensitive than other utilities; therefore, a protective damage risk criterion of 0.5 inch/second is being used for older cast-iron water mains (the Seattle Public Utilities standard).

3.11 Interagency Coordination

The noise and vibration methods and analysis developed for this Project are consistent with those developed for the Alaskan Way Viaduct and Seawall Replacement Program based on coordination between WSDOT, the City of Seattle, King County, and FHWA. During April 2002, a noise and vibration analysis approach was distributed to these agencies for review and comment. On April 17, 2002, the approach was presented to acoustic staff from WSDOT, the City of Seattle, and King County for comment and discussion. Input from these agencies was incorporated into the approach used in this study. On July 23, 2003, an update was presented to WSDOT and City of Seattle staff. Monitoring results were distributed to WSDOT and City of Seattle staff on August 26, 2003, to solicit any comments on field data prior to completion of the noise technical analysis. Inputs from these agencies were incorporated into the SR 99: Alaskan Way Viaduct & Seawall Replacement Project Draft Environmental Impact Statement (EIS) (WSDOT et al. 2004). The methods used in the 2004 Draft EIS are the same as those used in this study for the S. Holgate Street to S. King Street Viaduct Replacement Project.

Exhibit 4-2. Modeled Existing Traffic L_{eq}(h) Noise Levels

Receptor	Representative Noise-Sensitive Use	FHWA Activity Category (see Exhibit 3-6)	Noise Abatement Criteria (dBA)	Modeled Existing Peak Traffic Noise (dBA)
1	Shelter (212 capacity)	E	52	**51***
2	Third-story artist lofts (32 units)	E	52	50*
3	Temporary dining area	B	67	**68**
4	Outdoor dining area	B	67	**66**
5	209 hotel rooms	E	52	46*
6	235 residential units	B	67	**72**

* A reduction factor of 25 was applied to exterior calculated noise levels to estimate the interior noise levels.
Numbers in **BOLD** indicate noise levels that approach or exceed the FHWA noise abatement criteria.
See Exhibit 4-3 for receptor location.

The measurement for Site 1 was taken at ground level on the sidewalk between St. Martin de Porres Shelter and E. Marginal Way S. This site is representative of 212 shelter beds. Because this area has no outdoor use, interior noise levels were used to measure effects. Interior noise levels were calculated by applying the FHWA building noise reduction factor of 25 to exterior calculated noise levels at Sites 1, 2, and 5 (FHWA 1995).

The measurement at Site 2 was taken at ground level on the sidewalk at the corner of Colorado Avenue S. and S. Atlantic Street. Because this area has no ground-level use, a modeled receptor was placed at the third story of the Bemis Building. This area also has no outdoor use, therefore interior noise levels were used to measure effects. This site is representative of 32 artist lofts.

Site 3 was modeled to represent Ivar’s Clambake, a temporary dining area. The receptor is located near the southeast corner of First Avenue S. and S. Atlantic Street. Ivar’s Clambake is open only during 3-hour periods up to the opening pitches at home baseball games.

Site 4 was measured and modeled to represent an outdoor dining area at the Pyramid Alehouse, near the southwest corner of First Avenue S. and S. Royal Brougham Way.

Site 5 was modeled at the ground level on the sidewalk between the Silver Cloud Hotel and S. Royal Brougham Way. This site is representative of 209 hotel rooms with no outdoor use for the hotel rooms, therefore interior noise levels were used to measure effects. The 10^{th}-floor outdoor swimming pool at the Silver Cloud Hotel was noted, but because of its vertical distance from project roadways, it would not likely be affected by the Project and was therefore not considered a sensitive receiver.

Site 6 was measured and modeled on the fifth floor balcony of the Florentine Apartments. This site is representative of the outdoor use of 235 residential units, including the planned but currently not built Stadium Loft condominiums. This receptor faces First Avenue S. and the Alaskan Way Viaduct; noise levels could be lower for residential units facing different directions.

The peak traffic volumes for existing conditions were entered into the noise model, along with transit bus and truck percentages appropriate to each of the downtown streets. Modeled existing loudest hour L_{eq}(h) traffic noise levels at the receptor locations ranged between 67 and 75 dBA (Exhibit 4-2). Thus, the modeled existing traffic noise levels approach or exceed the FHWA noise abatement criteria. The modeled traffic-only noise level currently exceeds the exterior noise effect criteria at Sites 3, 4, and 6.

4.3 Existing Vibration Environment

Vibration levels generated by rubber-tired vehicles are usually not of concern for existing roadways. However, there are perceptible levels of ground vibration at the base of the vertical steel piers supporting the Alaskan Way Viaduct. This may be due to the mass and roadway span of the structure that, at some locations, is amplifying the vibration levels generated by heavy trucks passing by.

The closest buildings to the viaduct are commercial. To document the existing vibration environment in these areas, field measurements were carried out at a representative location beneath the viaduct. Existing vibration levels resulting from heavy vehicles on the viaduct were measured in one location to establish a baseline. This site along the viaduct represents the closest occupied buildings to the structure. The measured levels are presented in Exhibit 4-4 as maximum rms velocity vibration and PPV.

Exhibit 4-4. Ambient Vibration Levels along Alaskan Way Viaduct

Receiver ID	Location Description	Maximum Vibration Velocity Level (VdB)	Peak Particle Velocity Level (In/s)
V1	Viaduct near S. King Street	77.0	**0.035**

In/s = inches per second
Numbers in **BOLD** indicate vibration levels that exceed the annoyance criteria state in Exhibit 3-9.

These measurements were conducted at a building within 30 feet of a viaduct vertical pier (shown in Exhibit 4-5).

Chapter 5 OPERATIONAL EFFECTS AND MITIGATION

Long-term operational traffic noise levels with or without the Project were modeled for the year 2030. Future noise levels were similar under all future and existing conditions using the TNM.

5.1 Operational Noise Effects

Traffic noise levels in 2030 with or without the Project would be similar to current levels. Traffic patterns would not substantially change, and peak traffic volumes would increase only slightly because current peak-period traffic volumes are near the roadway system's capacity in the study area. Traffic noise levels would continue to approach or exceed the FHWA noise abatement criteria in the study area.

The modeled traffic noise levels approach or exceed the FHWA noise abatement criteria at three modeled sites, which represent approximately 235 residential units, a temporary dining area, and an outdoor dining area.

Exhibit 5-1. Modeled 2030 Peak Traffic L_{eq}(h) Noise Levels

Receptor	Representative Noise-Sensitive Use	FHWA Activity Category (see Exhibit 3-6)	Noise Abatement Criteria (dBA)	Without the Project (dBA)	With the Project (dBA)
1	Shelter (212 capacity)	E	52	**52***	50*
2	Third-story artist lofts (32 units)	E	52	50*	48*
3	Temporary dining area	B	67	**68**	**67**
4	Outdoor dining area	B	67	**69**	**68**
5	209 hotel rooms	E	52	47*	47*
6	235 residential units	B	67	**73**	**73**

* A reduction factor of 25 was applied to exterior calculated noise levels to estimate the interior noise levels.
Numbers in **BOLD** indicate noise levels that approach or exceed the FHWA noise abatement criteria.

Total noise levels at the modeled sites could be greater than the predicted traffic noise level because non-traffic sound sources may contribute to the total environmental noise level in the study area. Non-traffic noise sources at the sites included aircraft, sounds from businesses, sidewalk noise, construction noise, building mechanical noise, alarms, and sirens.

5.2 Operational Noise Mitigation

Noise can be controlled at three locations: (1) at the source (e.g., with mufflers and quieter engines), (2) along the noise path (e.g., with barriers, shielding, or increased distance), and (3) at the receptor (e.g., with insulation). Noise abatement is necessary only where frequent human use occurs and where a lower noise level would have benefits (USDOT 1982).

A variety of mitigation methods can be effective at reducing traffic noise effects. For example, noise effects from the long-term operation of the Project could be reduced by implementing traffic management measures, acquiring land as buffer zones or for construction of noise barriers or berms, realigning the roadway, and installing noise insulation for public use or nonprofit institutional structures. These mitigation measures were evaluated for their potential to reduce noise effects from the Project.

WSDOT evaluates many factors to determine whether mitigation would be feasible and reasonable. Determination of feasibility includes evaluating whether mitigation could be constructed in a location to achieve a noise reduction of at least 7 dBA at the closest receptors and a reduction of 5 dBA or more at most of the first row of receptors. Determination of reasonability includes determining the number of sensitive receptors benefited by at least 3 dBA and the cost-effectiveness of the mitigation. The reasonableness criteria for cost of noise mitigation provided per benefited receptor are summarized in Exhibit 5-2. For noise levels above 76 dBA, the allowed cost increases by $3,630 per dBA increase.

Exhibit 5-2. Mitigation Allowance for Noise Effects

Design Year Traffic Noise Decibel Level	Allowed Mitigation Cost Per Household	Allowed Wall Surface Area Per Household (at $53.40 / ft^2)
66 dBA	$37,380	700 sq. ft.
67 dBA	$41,110	768 sq. ft.
68 dBA	$44,640	836 sq. ft.
69 dBA	$48,270	904 sq. ft.
70 dBA	$51,900	972 sq. ft
71 dBA	$55,530	1,040 sq. ft.
72 dBA	$59,160	1,108 sq. ft.
73 dBA	$62,790	1,176 sq. ft.
74 dBA	$66,420	1,244 sq. ft
75 dBA	$70,060	1,312 sq. ft.
76 dBA	$73,690	1,380 sq. ft.

Source: WSDOT (2006).

5.2.1 Operational Noise Mitigation Options

Traffic Management Measures

Traffic management measures include time restrictions, traffic control devices, signing for prohibition of certain vehicle types (e.g., motorcycles and heavy trucks), modified speed limits, and exclusive lane designations. Noise effects could be reduced by land use controls throughout the Puget Sound region, but the study area is largely built out. A transportation system management plan combined with increased transit facilities to encourage the continued use of carpools and public transit would reduce vehicle trips and, subsequently, traffic noise. However, a 3-dBA decrease in traffic noise would require a reduction in traffic volume of approximately 50 percent.

Land Acquisition for Noise Buffers or Barriers

The study area is densely developed. Land acquisition for noise buffers or barriers in an urban area such as the study area would require relocating numerous residents and businesses and would not be reasonable for noise mitigation purposes.

Realigning the Roadway

The horizontal alignment is defined by available right-of-way and the existing Alaskan Way Viaduct corridor. The vertical alignment is defined by the design features of the Project. The cost of realigning the roadway would not be reasonable exclusively as a noise mitigation consideration.

Noise Insulation of Buildings

Insulation of buildings could be feasible, but this remedy only applies to structures with public or nonprofit uses (23 CFR 772 and 67 FR 13731, March 26, 2002). This remedy does not apply to commercial and residential structures, which constitute most uses within the project area. This option also would not reduce exterior noise effects.

Noise Barriers

Noise barriers include noise walls, berms, and buildings that are not noise-sensitive. The effectiveness of a noise barrier is determined by its height, length, and the Project site's topography. To be effective, the barrier must block the line of sight between the highest point of a noise source (e.g., a truck's exhaust stack) and the highest part of a receiver. It must be long enough to prevent sounds from passing around the ends, have no openings such as driveway connections, and be dense enough so that noise would not be transmitted through it. Intervening rows of buildings that are not noise-sensitive could also be used as barriers (USDOT 1973).

For a noise barrier to be built, it must be determined to be both feasible and reasonable (the criteria for which are discussed above under Section 5.2). Exhibit 5-2 summarizes the mitigation allowance for barrier area provided per benefited receptor that is considered reasonable in accordance with WSDOT policy.

However, traffic noise effects in the study area occur as a result of high traffic volumes on the urban arterial grid. Mitigation of traffic noise levels by construction of a noise barrier is not feasible in this area because most of the traffic noise is generated by arterial traffic on the city street grid. A continuous wall would need to be constructed along the city streets, and such a barrier would cut off access to too much of the city street grid.

5.2.2 Mitigation of Traffic Noise on Affected Receivers

Traffic noise levels already approach or exceed noise abatement criteria in the study area as a result of general traffic on the urban arterial grid independent of traffic noise generated by the Alaskan Way Viaduct.

Traffic noise effects in the study area occur as a result of high traffic volumes on the urban arterial grid. Traffic speeds are already low, and transit ridership is high. Future traffic noise levels are predicted to decrease by as much as 2 dBA and increase in other areas by up to 1 dBA; therefore, noise levels would not change substantially in this area as a result of the Project. Mitigation of traffic noise levels is not feasible in this area because the majority of the traffic noise is generated by arterial traffic on the city street grid.

5.3 Operational Vibration Effects

While existing vibration levels are above the annoyance criteria for the land uses in the area, long-term vibration levels with the Project are expected to decrease from the existing levels because the new viaduct structure would be in a similar location and would have a similarly configured but strengthened support structure and a smoother roadway surface compared to the existing viaduct. Vibration levels with the Project are expected to be below the annoyance criteria for the land uses in the area, so no vibration effects are expected due to operation of the Project.

5.4 Operational Vibration Mitigation

Annoyance effects from vibration are not expected to occur inside buildings from operation of the Project, so no mitigation would be necessary.

Chapter 6 CONSTRUCTION EFFECTS AND MITIGATION

In developing the construction sequencing for this Project, the proposed action was broken down into a series of traffic stages that represent significant changes to traffic flow and routes within the project corridor, such as detours or lane or roadway closures. Each traffic stage includes a set of construction activities that must be substantially completed prior to moving into the next traffic stage and the subsequent construction activities. The construction period for this Project would consist of approximately 8 months of early utility relocations and five traffic stages of major construction; the overall duration would be approximately 4 years and 4 months.

Construction may occur up to 24 hours per day, 7 days per week at times during the construction period, but would typically take place 5 days per week, 10 hours per day. Some night or weekend work may be required for roadway crossings, tail track relocation, or other critical construction phases. Nighttime work would require temporary noise variances from the City of Seattle Department of Planning and Development. Temporary noise variances would be applied for prior to any nighttime work.

The construction methods for this Project are described in the Technical Description and Construction Methods Technical Memorandum. The actual construction sequence could differ substantially from this evaluation; however, the locations and types of activities would be similar in the final sequence.

Construction of the bridges, street-level facilities, and retained cuts that would compose the new SR 99 and ramps would require the following activities:

- Demolition and removal of materials
- Support wall construction
- Ground improvements
- Substructure installations
- Retained fill construction
- Retained cut construction

6.1 Construction Noise Effects

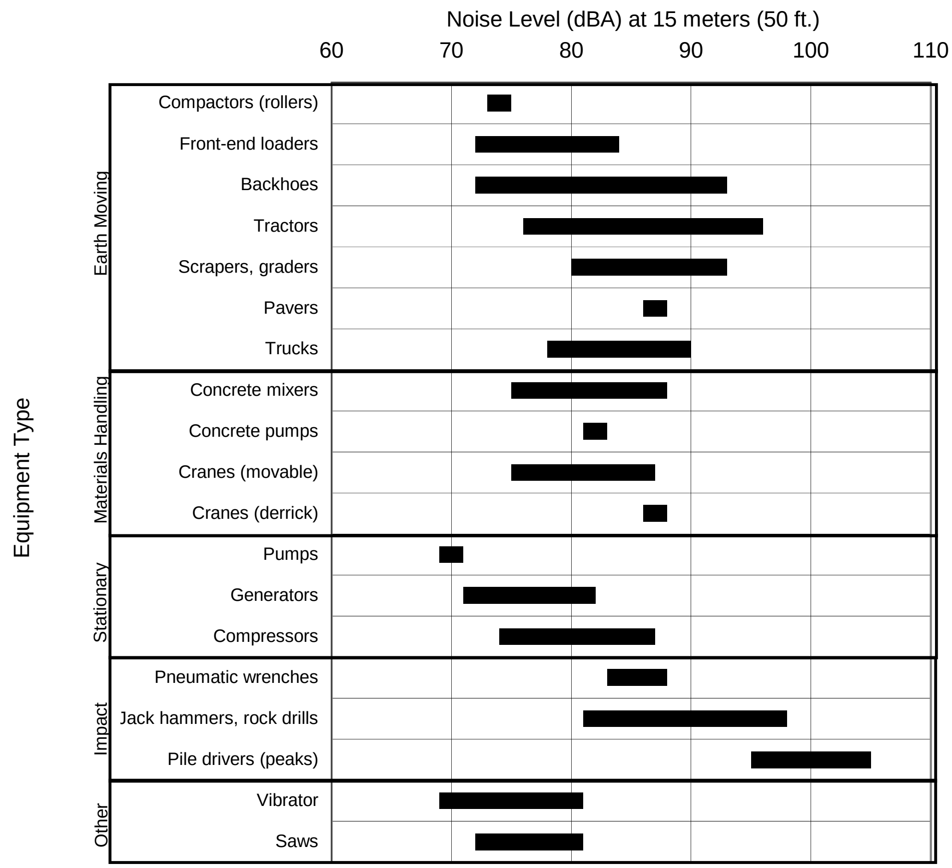
Removal of the existing viaduct would be the loudest activity for residents from S. Holgate Street to S. King Street. Construction noise would be bothersome to nearby residents and businesses. Construction noise would vary widely, both spatially and temporally over the course of the Project. The construction period is anticipated to last approximately 52 months, with various periods of disturbance that would last for several weeks in any one area.

The most prevalent noise source at construction sites would be internal combustion engines. Earth-moving equipment, material-handling equipment, and stationary equipment are all engine-powered. Mobile equipment operates in a cyclic fashion, but stationary equipment (e.g., pumps, generators, and compressors) operates at sound levels that are fairly constant over time. Because trucks would be present during most phases and would not be confined to the project site, noise from trucks could affect more receptors. Other noise sources would include impact equipment and tools such as pile drivers. Impact tools could be pneumatically powered, hydraulic, or electric.

Construction noise would be intermittent, occurring at different times over an approximate 52-month period at various locations in the study area. Construction noise levels would depend on the type, amount, and location of construction activities. The construction methods establish the maximum noise levels of construction equipment used. The amount of construction activity would quantify how often construction noise would occur throughout the day. The location of construction equipment relative to adjacent properties would determine any effects of distance in reducing construction noise levels. The maximum noise levels of construction equipment would be similar to the typical maximum construction equipment noise levels presented in Exhibit 6-1.

As shown in Exhibit 6-1, maximum noise levels from construction equipment would range from 69 to 106 dBA L_{max} at 50 feet. Construction noise at locations farther away would decrease at a rate of 6 to 8 dBA per doubling of distance from the source. The number of occurrences of the L_{max} noise peaks would increase during construction, particularly during pile-driving activities. Because various pieces of equipment would be turned off, idling, or operating at less than full power at any given time, and because construction machinery is typically used to complete short-term tasks at any given location, average L_{eq} daytime noise levels would be 10 to 20 dBA less than the maximum noise levels presented in Exhibit 6-1. Construction noise levels may not exceed a maximum L_{eq}(7.5 minutes) of 99 dBA at 50 feet or the nearest property line (whichever is farther) within the city of Seattle.

Construction noise is allowed to exceed City of Seattle (SMC 25.08.425) property-line noise limits by 20 to 25 dBA during daytime hours (7 a.m. to 10 p.m. on weekdays and 9 a.m. to 10 p.m. on weekends). The use of impact equipment is also not allowed between the hours of 8 a.m. to 5 p.m. on weekdays and between 9 a.m. and 5 p.m. on weekends. During construction, noise from certain activities is likely to exceed the higher daytime limits during some construction stages. Nighttime construction that would exceed nighttime noise limits may also be required. To accommodate these exceedances of the City of Seattle noise regulations, the Project would apply for nighttime noise variances from the City of Seattle.



Source: EPA 1971.

Exhibit 6-1. Typical Construction Equipment Noise Levels

6.2 Construction Noise Mitigation

Construction of the Project may require nighttime construction activities or exceed daytime noise level limits; therefore, a noise variance may be required from the City of Seattle. If a noise variance is required, construction noise mitigation methods would be developed in coordination with the City and specified in the noise variance. To reduce construction noise at nearby receptors, mitigation measures such as the following could be incorporated into construction plans, specifications, and variance requirements:

- Crush and recycle concrete off-site, away from noise-sensitive uses, to decrease construction noise effects. If recycled on-site, an operations plan would be required to define the locations and hours of operations.
- Construct temporary noise barriers or curtains around stationary equipment and long-term work areas that must be located close to residences. This would decrease noise levels at nearby sensitive receptors and could reduce equipment noise by 5 to 10 dBA.
- Limit the noisiest construction activities to between 7 a.m. and 10 p.m. on weekdays and between 9 a.m. and 10 p.m. on weekends to reduce construction noise levels during sensitive nighttime hours. A noise variance would be required from the City of Seattle for construction between 10 p.m. and 7 a.m. on weekdays and between 10 p.m. and 9 a.m. on weekends.
- Limit the use of impact equipment to between the hours of 8 a.m. to 5 p.m. on weekdays and between 9 a.m. and 5 p.m. on weekends. A noise variance would be required from the City of Seattle for the use of impact equipment between 5 p.m. and 8 a.m. on weekdays and between 5 p.m. and 9 a.m. on weekends.
- Equip construction equipment engines with adequate mufflers, intake silencers, and engine enclosures; this could reduce their noise by 5 to 10 dBA.
- Use the quietest equipment available; this could reduce noise by 5 to 10 dBA.
- Use manually adjustable or automatic ambient sound-level sensing backup alarms approved by the Occupational Safety and Health Administration (OSHA). These alarms are 10 to 20 dBA quieter than standard alarms, which could reduce disturbances to nearby residents from backup alarms during quieter periods.
- Use broadband alarms, strobes, or back observers in lieu of pure tone backup warning devices for nighttime work.
- Turn off construction equipment during prolonged periods of non-use; this could eliminate noise from construction equipment during those periods.
- Maintain all equipment and train equipment operators; this could reduce noise levels and increase operational efficiency. Out-of-specification mufflers can increase equipment noise by 10 to 20 dBA.

- Where possible, locate stationary equipment away from noise-sensitive receiving properties.
- Notify nearby residents prior to periods of intense nighttime construction.
- Where amenable, provide heavy window coverings or other temporary soundproofing material on adjacent buildings for nighttime noise-sensitive locations where prolonged periods of intense nighttime construction would occur.

6.3 Construction Vibration Effects

The construction activities that would result in the highest levels of ground vibration are the demolition of the existing viaduct structure and impact pile driving. This Project would require the demolition and removal of all viaduct structures south of the intersection of Railroad Way S. and Alaskan Way S. In general, the viaduct would be demolished using various methods of concrete removal (including saw cutting and lifting segments out of place), using concrete pulverizers and shears mounted on excavators, or using concrete splitters, jackhammers, or hoe rams to break up concrete.

The use of jackhammers and hoe rams would result in the highest levels of vibration during the demolition activities. The expected PPV of ground vibration levels at 25 feet from the demolition activities ranges from 0.24 to 0.42 inch/second (Exhibit 6-2). This would exceed the damage risk criterion of 0.12 inch/second for older extremely fragile buildings but would not exceed the Project's damage risk criterion for newer buildings of 0.50 inch/second. Demolition activities conducted 100 feet or more from existing structures would not exceed the damage risk criterion for older extremely fragile buildings. Structures in the study area that may be extremely fragile include unrestored areaways, the spaces beneath the sidewalks of older buildings, and historic buildings that have not been structurally retrofitted.

During impact pile driving, the PPV of ground vibration levels at 25 feet is expected to be in the range of 0.60 to 1.9 inches/second, depending on the size and force exerted by the pile driver (Exhibit 6-3). These levels would substantially exceed the damage risk criteria of 0.12 inch/second for older extremely fragile buildings and 0.50 inch/second for newer buildings. At distances of 400 feet or more, the damage risk is significantly lower and is expected not to exceed 0.10 inch/second.

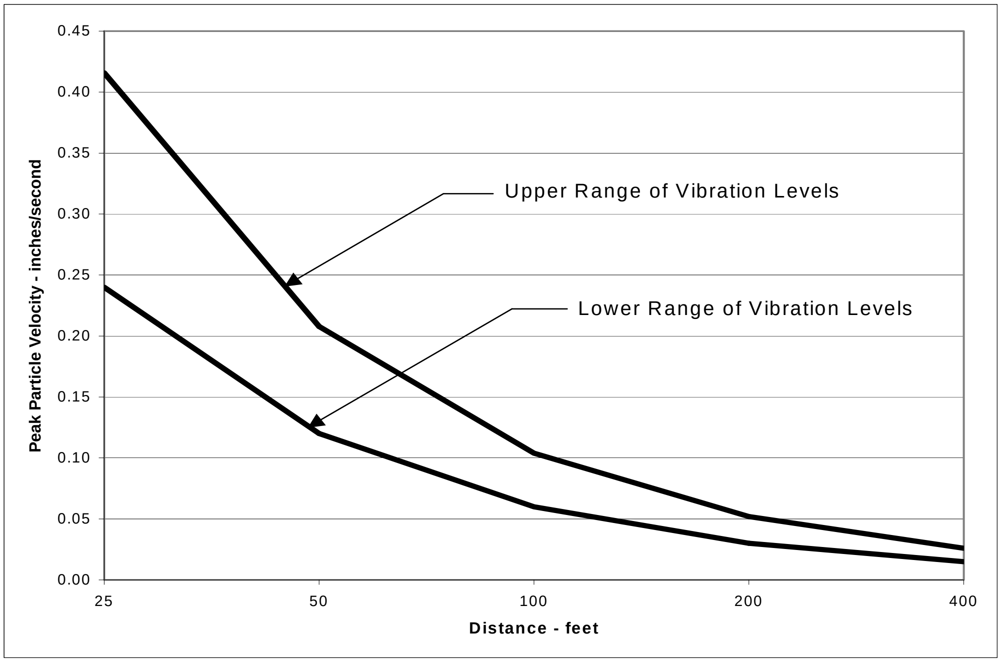


Exhibit 6-2. Hoe Ram and Jack Hammer Vibration Levels

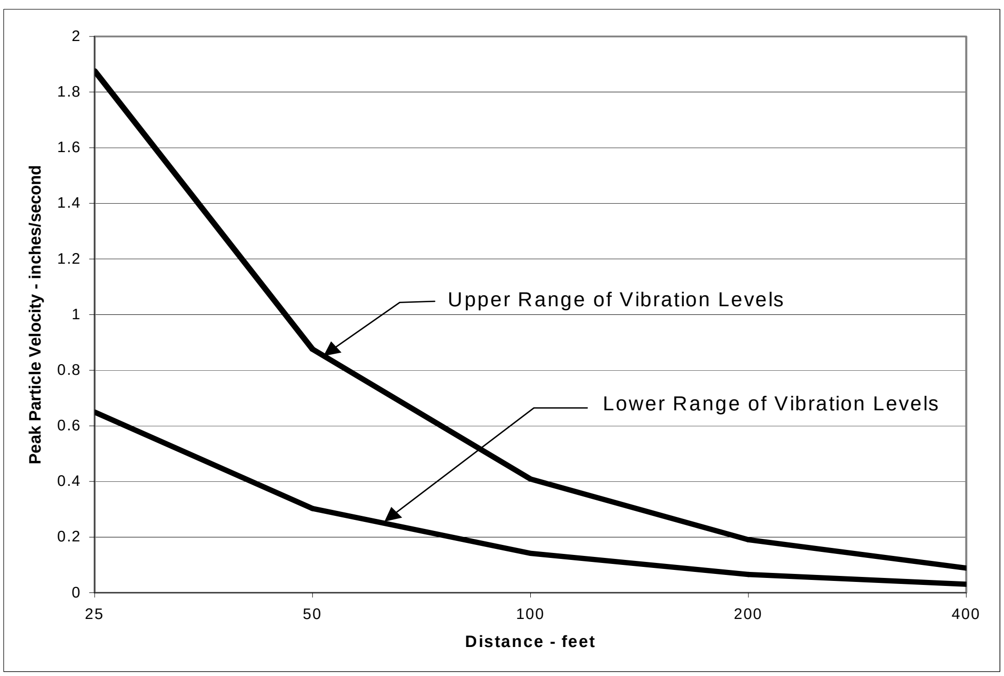


Exhibit 6-3. Impact Pile Driving Vibration Levels

In general, the potential effect to underground and buried utilities from construction vibration would be less than the damage risk to buildings. The only construction activity proposed for this Project that would generate vibration levels that could damage utilities would be impact pile driving. Vibration from pile driving would not exceed the damage risk criterion for most buried utilities of 4.0 inches/second PPV at distances greater than 25 feet or the damage risk criterion of 0.5 inch/second PPV for older cast-iron water mains at distances greater than 100 feet. The damage risk to buried utilities less than 25 feet and older cast-iron water mains less than 100 feet from impact pile driving locations should be further evaluated during final design.

6.4 Construction Vibration Mitigation

Impact pile driving would be the most significant source of vibration for this Project. Potential measures to reduce vibration from impact pile driving that can be used, when appropriate for specific site conditions, are as follows:

- Jetting – The use of a mixture of air and water pumped through a high-pressure nozzle to erode soil adjacent to the pile to facilitate placement of the pile.
- Pre-drilling – Pre-drilling a hole for a pile can be used to place the pile at or near its design depth, eliminating most or all impact driving.
- Cast-in-place or auger piles – Eliminates impact driving and limits vibration to the lower levels generated by drilling.
- Pile cushioning – A resilient material placed between the driving hammer and the pile.
- Alternative non-impact drivers – Several types of proprietary pile-driving systems have been designed specifically to reduce the impact-induced vibration by using torque and down-pressure or hydraulic static loading. These methods would be expected to significantly reduce adverse vibration effects from pile placement.
- Use of vibratory pile drivers instead of impact drivers.

Vibration from other construction activities can be reduced by either restricting their operation to predetermined distances from historic structures (such as the Triangle Hotel, 551 First Avenue S.) or other sensitive receivers, or using alternative equipment or construction methods. An example would be the use of saws or rotary rock cutting heads to cut bridge decks or concrete slabs instead of a hoe ram.

WSDOT would require vibration monitoring at the nearest historic structure or sensitive receiver to the construction activities. The monitored data will be compared to the Project's vibration criteria to ensure that ground vibration levels do not exceed the damage risk criteria for historic and non-historic buildings.

Chapter 7 INDIRECT AND CUMULATIVE EFFECTS

7.1 Indirect Effects

Indirect effects are reasonably foreseeable effects of an action that occur later in time or are farther removed in distance from the direct effects of the Project. Generally, these effects are induced by the initial action.

Indirect effects to the audible environment during construction are considered unlikely, and any effects would be limited because most of the construction activities would be confined to the study area. Indirect effects to the audible environment in the built condition are also unlikely because the Project would not increase the existing roadway system's capacity, and noise levels in the area would remain the same or decrease slightly with the Project.

7.2 Cumulative Effects

Cumulative effects are additive effects of the Project with other developments or actions in the past, present, or reasonably foreseeable future.

7.2.1 Operational Effects

The traffic noise analysis for the Project is based on the transportation demand forecasting model and therefore considers the long-term cumulative traffic noise from future traffic on both the Alaskan Way Viaduct and the Seattle street grid. Because arterial traffic noise is the dominant noise source in the study area, this analysis already evaluates the cumulative future noise environment. No additional cumulative effects have been identified for the built condition.

7.2.2 Construction Effects

During construction, several other projects are expected to be under construction downtown, including the SR 519 Intermodal Access Project Phase 2. If construction of other projects is within the immediate vicinity (less than approximately 1,000 feet) of construction areas for the Project and occurs at the same time, cumulative noise effects on nearby residents could increase in those areas. However, simultaneous construction of other projects within this proximity is not expected to occur very often or for very long duration.

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