September 2024

West Seattle Link Extension

Final Environmental Impact Statement

NOISE AND VIBRATION TECHNICAL REPORT

Appendix N.3

SoundTransit
U.S. Department of Transportation
Federal Transit Administration

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Appendix N.3

Noise and Vibration Technical Report

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West Seattle Link Extension Noise and Vibration Technical Report

September 2024

Sound Transit

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Acronyms and Abbreviations

Acronym	Definition
Ccurv	force density level
dB	decibel(s)
dBA	A-weighted decibel(s)
EIS	Environmental Impact Statement
FTA	Federal Transit Administration
FTA Guidance Manual	*Transit Noise and Vibration Impact Assessment Manual*
I.D.	identification
Krad	sound pressure level
Ldn	day-night equivalent sound level
Leq	equivalent sound level
Lmax	maximum sound level
Lv	vibration velocity
Sound Transit	Central Puget Sound Regional Transit Authority
V.C.	vibration criteria
VdB	vibration velocity decibel(s)
WSDOT	Washington State Department of Transportation

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1 INTRODUCTION

1.1 Overview

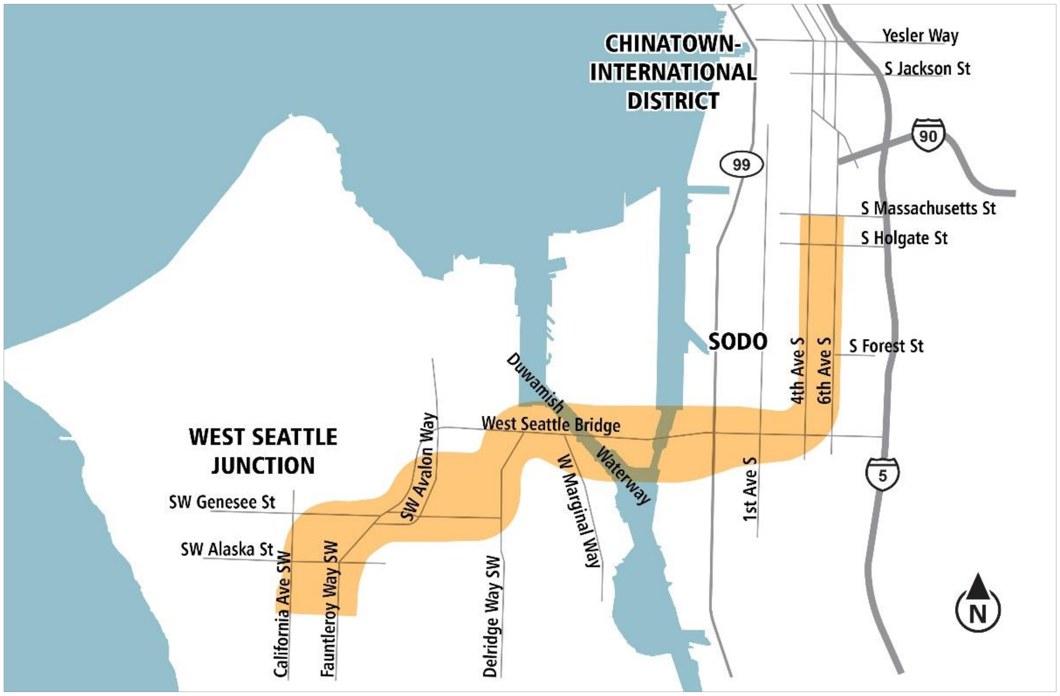
Central Puget Sound Regional Transit Authority (Sound Transit) is proposing to expand Link light rail transit service from SODO to West Seattle. The West Seattle Link Extension Project (the project) is a 4.1-mile corridor in the city of Seattle in King County, Washington, the most densely populated county of the Puget Sound region (Figure 1-1). The project would include stations at SODO, Delridge, Avalon, and Alaska Junction. The project is part of the Sound Transit 3 Plan of regional transit system investments, funding for which was approved by voters in the region in 2016.

The Draft Environmental Impact Statement (EIS) published in January 2022 evaluated both the West Seattle Link Extension and the Ballard Link Extension together as one West Seattle and Ballard Link Extensions (WSBLE) Project. The extensions were evaluated together in the WSBLE Draft EIS because of their location, schedule, and review efficiencies for partner agencies.

In July 2022, the Sound Transit Board directed that further studies be prepared for the Ballard Link Extension, to evaluate additional station options and other refinements (Motion M2022-57). Some of these project options and refinements require additional conceptual engineering and environmental review. Rather than delay completion of the environmental review process for the West Seattle Link Extension while additional review is conducted for the Ballard Link Extension, Sound Transit and Federal Transit Administration (FTA) have decided to move forward under separate environmental reviews for each extension.

As described in the WSBLE Draft EIS, the two extensions will operate as separate lines, and the extensions are standalone projects with independent utility. Proceeding with separate environmental review processes for each extension enables Sound Transit and FTA to minimize delay in delivering the West Seattle Link Extension while further analysis is undertaken on the Ballard Link Extension. Accordingly, this Final EIS is for the West Seattle Link Extension only. The Ballard Link Extension will undergo separate environmental review, building on the analysis that has already been completed.

Figure 1-1. West Seattle Link Extension Project Corridor



The West Seattle Link Extension would provide fast, frequent, and reliable light rail in Seattle and connect dense residential and job centers throughout the Puget Sound region. The Puget Sound Regional Council (the regional metropolitan planning organization) and the City of Seattle have designated the following Manufacturing/Industrial Center and urban village in the project corridor:

- **Manufacturing/Industrial Center.** The project corridor includes the Duwamish Manufacturing/ Industrial Center. SODO Station is in the Duwamish Manufacturing/Industrial Center.
- **Urban Village.** West Seattle Junction is a neighborhood in the project corridor designated by the City of Seattle as an urban village. The Alaska Junction and Avalon stations are in the West Seattle Junction Urban Village.

Puget Sound Regional Council

Puget Sound Regional Council, the regional metropolitan planning organization, develops policies and coordinates decisions about regional growth, transportation, and economic development planning within King, Kitsap, Pierce, and Snohomish counties. Puget Sound Regional Council is composed of over 80 jurisdictions, including all four counties; cities and towns; ports; state and local transportation agencies; and tribal governments within the region.

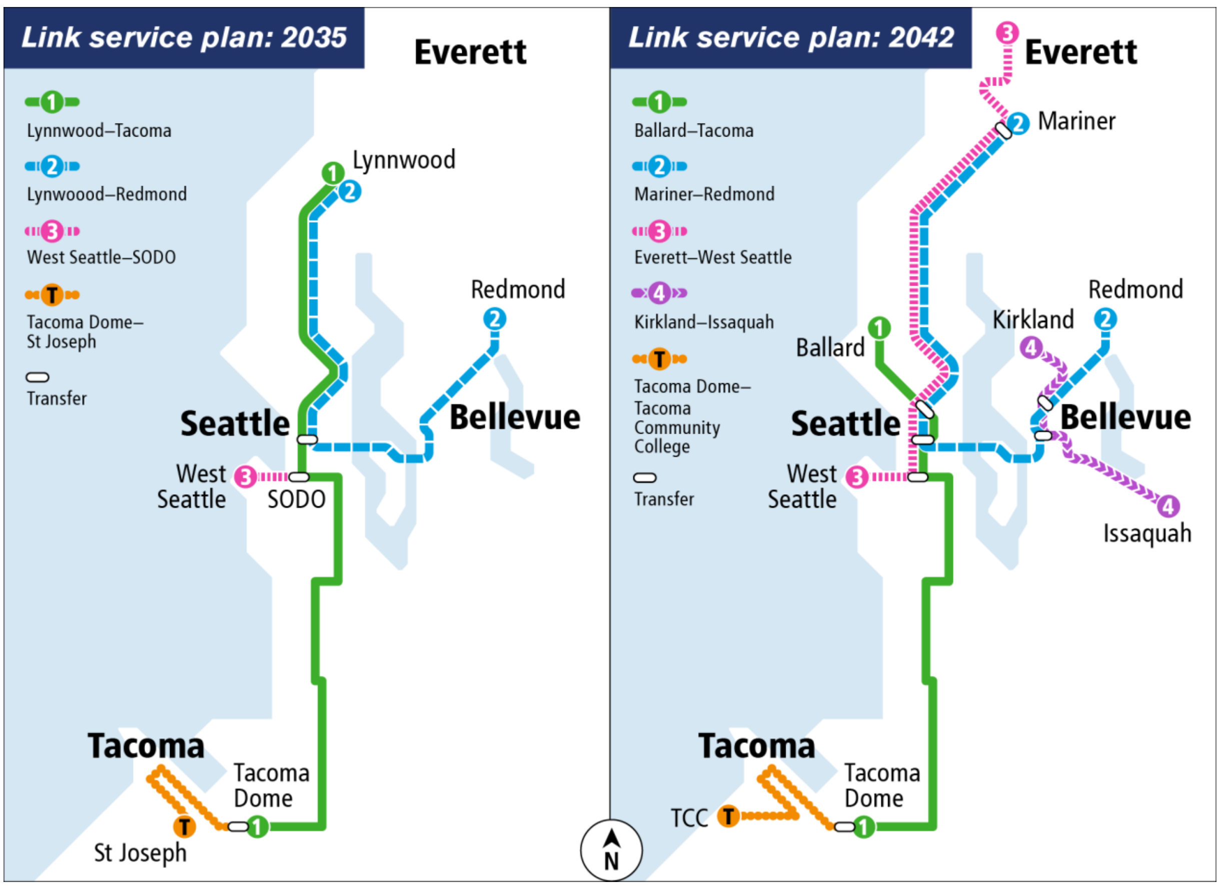
These designations indicate that these areas will continue to increase in residential and/or employment density over the next 30 years.

Existing local transit connections in the project corridor include bus and light rail. The King County Metro Transit (Metro) RapidRide C bus line currently provides service between West Seattle, Downtown Seattle, and South Lake Union. The RapidRide H bus line provides service between Burien and Downtown Seattle via Delridge. Other local bus service also operates in the project corridor.

Regional transit service in the project corridor includes regional bus service, ferry service, light rail, Sounder commuter rail, and Amtrak passenger rail service. Light rail currently operates between the Angle Lake Station in the city of SeaTac and Northgate Station in Seattle, traveling through the Downtown Seattle Transit Tunnel. There is an existing light rail station in SODO in the West Seattle Link Extension Corridor.

Extensions of light rail are under construction north to Lynnwood, east to Bellevue and Redmond, and south to Federal Way, all of which are anticipated to be operational by 2026. Additional planned light rail extensions would continue south to the Tacoma Dome, expected to begin service in 2035, and north to Everett, planned to begin service between 2037 and 2041. The Ballard Link Extension is scheduled to begin service between SODO and Ballard in 2039. The West Seattle Link Extension is scheduled to open in 2032 and would include a new SODO station where riders to and from West Seattle could transfer to the existing SODO station and light rail system until the Ballard Link Extension begins operation. The Ballard Link Extension would permanently connect the West Seattle Link Extension to the existing 1 Line, allowing riders to continue north to Everett. Figure 1-2 shows the full system planned for operation in 2042 under the target schedule. Table 1-1 lists the project Build Alternatives.

Figure 1-2. Link Light Rail System Expansion



1.2 Purpose of Report

The purpose of this report is to document noise and vibration in the project vicinity and evaluate potential impacts associated with the proposed alternatives. This report covers both noise and vibration in the study area.

Table 1-1. Summary of West Seattle Link Extension Build Alternatives

Segment	Alternatives and Design Options	Abbreviation	Stations (and Station Profile)	Connections
SODO	**Preferred At-Grade Lander Access Station Option**	**SODO-1c**	**SODO (At-Grade)**	**All Duwamish Segment alternatives.**
SODO	At-Grade Alternative	SODO-1a	SODO(At-Grade)	All Duwamish Segment alternatives.
SODO	At-Grade South Station Option	SODO-1b	SODO (At-Grade)	All Duwamish Segment alternatives.
SODO	Mixed Profile Alternative	SODO-2	SODO (Elevated)	All Duwamish Segment alternatives.
Duwamish (DUW)	**Preferred South Crossing Alternative**	**DUW-1a**	**None**	**All SODO Segment alternatives. All Delridge Segment alternatives.**
Duwamish (DUW)	South Crossing South Edge Crossing Alignment Option	DUW-1b	None	All SODO Segment alternatives. All Delridge Segment alternatives.
Duwamish (DUW)	North Crossing Alternative	DUW-2	None	All SODO Segment alternatives. All Delridge Segment alternatives.
Delridge (DEL)	**Preferred Andover Street Station Lower Height South Alignment Option**	**DEL-6b**	**Delridge (Elevated)**	**All Duwamish Segment alternatives. Connects to WSJ-5a and WSJ-5b.**
Delridge (DEL)	Dakota Street Station Alternative	DEL-1a	Delridge (Elevated)	All Duwamish Segment alternatives. Connects to WSJ-1, WSJ-2, and WSJ-4.
Delridge (DEL)	Dakota Street Station North Alignment Option	DEL-1b	Delridge (Elevated)	All Duwamish Segment alternatives. Connects to WSJ-1, WSJ-2, and WSJ-4.
Delridge (DEL)	Dakota Street Station Lower Height Alternative	DEL-2a	Delridge (Elevated)	All Duwamish Segment alternatives. Connects to WSJ-3a and WSJ-3b.
Delridge (DEL)	Dakota Street Station Lower Height North Alignment Option	DEL-2b	Delridge (Elevated)	All Duwamish Segment alternatives. Connects to WSJ-3a and WSJ-3b.
Delridge (DEL)	Delridge Way Station Alternative	DEL-3	Delridge (Elevated)	All Duwamish Segment alternatives. Connects to WSJ-1, WSJ-2, and WSJ-4.
Delridge (DEL)	Delridge Way Station Lower Height Alternative	DEL-4	Delridge (Elevated)	All Duwamish Segment alternatives. Connects to WSJ-3a and WSJ-3b.

Segment	Alternatives and Design Options	Abbreviation	Stations (and Station Profile)	Connections
Delridge (DEL)	Andover Street Station Alternative	DEL-5	Delridge (Elevated)	All Duwamish Segment alternatives. Connects to WSJ-1, WSJ-2, and WSJ-4.
Delridge (DEL)	Andover Street Station Lower Height Alternative	DEL-6a	Delridge (Elevated)	All Duwamish Segment alternatives. Connects to WSJ-5a and WSJ-5b.
Delridge (DEL)	Andover Street Station Lower Height No Avalon Station Tunnel Connection Alternative	DEL-7	Delridge (Elevated)	All Duwamish Segment alternatives. Connects to WSJ-6.
West Seattle Junction (WSJ)	**Preferred Medium Tunnel 41st Avenue Station West Entrance Station Option**	**WSJ-5b**	**Avalon (Retained Cut), Alaska Junction (Tunnel)**	**Connects to DEL-6a and DEL-6b.**
West Seattle Junction (WSJ)	Elevated 41st/42nd Avenue Station Alternative	WSJ-1	Avalon (Elevated), Alaska Junction (Elevated)	Connects to DEL-1a, DEL-1b, DEL-3, and DEL-5.
West Seattle Junction (WSJ)	Elevated Fauntleroy Way Station Alternative	WSJ-2	Avalon (Elevated), Alaska Junction (Elevated)	Connects to DEL-1a, DEL-1b, DEL-3, and DEL-5.
West Seattle Junction (WSJ)	Tunnel 41st Avenue Station Alternative	WSJ-3a	Avalon (Tunnel), Alaska Junction (Tunnel)	Connects to DEL-2a, DEL-2b, and DEL-4.
West Seattle Junction (WSJ)	Tunnel 42nd Avenue Station Option	WSJ-3b	Avalon (Tunnel), Alaska Junction (Tunnel)	Connects to DEL-2a, DEL-2b, and DEL-4.
West Seattle Junction (WSJ)	Short Tunnel 41st Avenue Station Alternative	WSJ-4	Avalon (Elevated), Alaska Junction (Tunnel)	Connects to DEL-1a, DEL-1b, DEL-3, and DEL-5.
West Seattle Junction (WSJ)	Medium Tunnel 41st Avenue Station Alternative	WSJ-5a	Avalon (Retained Cut), Alaska Junction (Tunnel)	Connects to DEL-6a and DEL-6b.
West Seattle Junction (WSJ)	No Avalon Station Tunnel Alternative	WSJ-6	Alaska Junction (Tunnel)	Connects to DEL-7.

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2 ENVIRONMENTAL NOISE AND VIBRATION BASICS

2.1 Noise Fundamentals and Descriptors

2.1.1 Understanding Sound

What humans perceive as sound is a series of continuous air pressure fluctuations superimposed on the atmospheric pressure that surrounds us. The amplitude of fluctuation is related to the energy carried in a sound wave; the greater the amplitude, the greater the energy, and the louder the sound. The full range of sound pressures encountered in the world is so great that it is more convenient to compress the range by using a logarithmic scale, resulting in the fundamental descriptor used in acoustics—the sound pressure level, which is measured in decibels (dB). When sounds are unpleasant, unwanted, or disturbingly loud, one tends to classify them as noise.

Another aspect of sound is the quality described as its pitch. Pitch of a sound is established by the frequency, which is a measure of how rapidly a sound wave fluctuates. The unit of measurement is cycles per second, called hertz. When a sound is analyzed, its energy content at individual frequencies is displayed over the frequency range of interest, usually the range of human audibility from 20 to 20,000 hertz. This display is called a frequency spectrum.

Sound is measured using a sound level meter with a microphone designed to respond accurately to all audible frequencies. However, the human hearing system does not respond equally to all frequencies. Low-frequency sounds below about 400 hertz are progressively and severely attenuated, as are high frequencies above 10,000 hertz. To approximate the way humans interpret sound, a filter circuit with frequency characteristics similar to the human hearing mechanism is built into sound level meters. Measurements with this filter enacted are called A-weighted sound levels, expressed in A-weighted decibels (dBA). Community noise is usually characterized in terms of the A-weighted sound level.

The range of human hearing extends from about 0 dBA for young healthy ears (that have not been exposed to loud noise sources) to about 140 dBA. When sounds exceed 110 dBA, there is a potential for hearing damage, even with relatively short exposures. In quiet suburban areas far from major freeways, the noise levels during the late-night hours will drop to about 30 dBA. Outdoor noise levels lower than this only occur in isolated areas where there is a minimum amount of natural noises, such as leaves blowing in the wind, crickets, or flowing water. Table 2-1 provides a list of different sounds, activities and transportation noise sources and the maximum noise levels typically experienced in dBA.

Another characteristic of environmental noise is that it is constantly changing. The noise level increasing when a train passes is an example of a short-term change. The lower average noise levels occur during nighttime hours, when activities are at a minimum, with higher noise levels during daytime hours caused by daily patterns of noise-level fluctuation. The instantaneous A-weighted sound level is insufficient to describe the overall acoustic environment. Thus, it is common practice to condense the fluctuating noise levels into a single number, called the equivalent sound level (Leq).

Table 2-1. Examples of Common Noise Sources and General Noise Levels

Maximum Noise Level (approximate)	Examples of Sounds, Activities, and Transportation Noise Sources, Quietest to Loudest
25 to 30 dBA	Acoustic test chamber Quiet, rural area at night, crickets or wind noise, no traffic
30 to 40 dBA	Quiet bedroom with no air systems running Empty recording studio
40 to 50 dBA	Quiet window air conditioner, indoors Background noise inside a typical office space
50 to 60 dBA	Normal conservation, two people at 4 to 6 feet Typical television volume at 10 feet
60 to 70 dBA	Automobile cruising, 50 miles per hour, 50 feet Heated conservation, two to four people, 4 to 6 feet
70 to 80 dBA	Vanpool bus cruising, 50 miles per hour, 50 feet Medium truck (parcel delivery trucks) at 50 miles per hour, 50 feet
86 dBA	Link light rail, 4-car train traveling at 55 miles per hour, measured at 50 feet
80 to 90 dBA	Overland bus cruising, 50 miles per hour, 50 feet Accelerating heavy loaded truck, 50 feet
90 to 100 dBA	Multiple locomotives pulling 5000 feet train. 40 miles per hour, 100 feet Loud shop tools (router, table saw), 5 feet
Over 100 dBA	Loud crowd at an indoor basketball game Freight train horn at 100 feet Jet takeoff at 250 feet

Source: Adapted from FTA (2018) and measured noise levels. Link light rail noise levels from measurements in 2018 and 2019.

Leq can be thought of as the steady sound level that represents the same sound energy as the varying sound levels over a specified time period (typically 1 hour or 24 hours). Often the Leq values over a 24-hour period are used to calculate cumulative noise exposure in terms of the day-night equivalent sound level (Ldn), which is defined as the 24-hour Leq but with a 10-dB penalty added to each nighttime hourly Leq (with nighttime defined as the period from 10 p.m. to 7 a.m.). The effect of this penalty is that any event during the nighttime is equivalent to 10 events during the daytime. This strongly weights Ldn toward nighttime noise to reflect most people being more easily annoyed by noise at night when background noise is lower, and most people are resting.

Environmental impact assessments for mass transit projects in the United States typically use Ldn to describe the community noise environment at residential locations. Studies of community response to a wide variety of noises indicate that Ldn is a good measure of the noise environment. Table 2-2 defines typical community noise levels in terms of Ldn. Most urban and suburban neighborhood Ldn noise levels range from 50 to 70 dBA. An Ldn of 70 dBA is a relatively noisy environment that might be found at buildings on a busy surface street, close to a freeway, or near a busy airport and would usually be considered unacceptable for residential land use without special measures taken to enhance outdoor-indoor sound insulation. Residential neighborhoods that are not near major sound sources are usually in the range of Ldn 55 to 60 dBA. If there is a freeway or moderately busy arterial nearby, or any nighttime noise, Ldn is usually in the range of 60 to 65 dBA.

Table 2-2. Typical 24-hour Day-night Sound Levels and Land Use Compatibility

Day-Night Equivalent Noise Level in A-weighted Decibels	Description of Typical and Acceptable Land Use
Ldn below 50 dBA	Typically found in rural areas with no major roadways or other major noise sources nearby. Compatible with all noise-sensitive properties.
Ldn of 50 to 55 dBA	Typically found in quiet suburban residential neighborhoods not near any major roadways and with little nighttime activity. Compatible with all noise-sensitive properties.
Ldn of 55 to 60 dBA	Typically found in many residential areas with minor arterial roadways nearby, typical of many close in suburban and some urban residential areas. Compatible with all noise-sensitive properties.
Ldn of 60 to 65 dBA	Relatively noisy residential area. Usually a major road or airport is nearby. Considered normally acceptable for residential land use.
Ldn of 65 to 70 dBA	Noise levels in this range are typical for a noisy residential area that is close to a major freeway or the end of an airport runway. Considered marginally acceptable for a residential area.
Ldn of 70 to 75 dBA	Typical for areas directly adjacent to a major freeway or very near an airport. Not normally acceptable for residential use without noise mitigation measures.
Ldn greater than 75 dBA	Noise levels above 75 dBA Ldn are not acceptable for residential use and are only found near the ends of airport runways and adjacent to major highways.

Source: Adapted from FTA 2018.

Ldn is the designated noise metric of choice for many federal agencies, including the Department of Housing and Urban Development, Federal Aviation Administration, FTA, and United States Environmental Protection Agency. Most federal and state agency criteria for noise impacts are based on some measurement of noise energy. For example, the Federal Aviation Administration and Department of Housing and Urban Development use Ldn and the Federal Highway Administration uses peak hour Leq. The noise impact criteria applicable to residential areas is included in the 2018 *FTA Transit Noise and Vibration Impact Assessment Manual* (FTA Guidance Manual) (FTA 2018) and uses both Leq and Ldn to characterize community noise.

2.1.2 Calculating Decibels

An important factor to recognize is that noise is measured on a decibel scale, and calculating the sound level for two noise sources is not achieved by simple addition. For example, combining two 60-dB noise sources does not give 120 dB (which is near the pain threshold), but yields 63 dB, which is lower than the volume at which most people listen to their TVs. For reference, if two noise sources are 10 dB apart, for example 50 dB and 60 dB, the sum of the two noise levels will simply be the louder of the two, in this case 60 dB. This is to say that for similar noise sources that are 10 dB apart in magnitude, a person would only be able to hear the louder of the two sources.

Examples of simplified decibel addition, based on the difference between the two levels, are provided in Table 2-3 for reference, to aid in the understanding of the total project noise and impact analysis presented in this report.

Table 2-3. Decibel Addition Approximations

Difference between the Two Noise Sources	Amount Added to the Higher of the Two Noise Levels
0 to 1 dB	3 dB
2 to 3 dB	2 dB
4 to 9 dB	1 dB
10 dB or more	0 dB

This information is important when considering the FTA criteria and what the total noise (existing and light rail noise) would be at any location. An increase of less than 3 dB is not typically perceptible to an average person. For example, if noise from light rail operations is 4 dB to 9 dB below the existing noise levels, the project-related increase in the total noise (light rail plus existing) would be approximately 1 dB or less, an increase which is not perceptible to an average person.

2.2 Vibration Fundamentals and Descriptors

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 light 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.

One potential community impact from a project like the West Seattle Link Extension is vibration that is transmitted from the tracks through the ground to 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 vibration velocity. Root mean square is defined as the square root of the average of the squared amplitude of the vibration signal. To avoid confusion with sound decibels, the abbreviation VdB is used for vibration velocity decibels. All vibration decibels in this report use a decibel reference of 1 micro-inch per second.

The potential 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.
- 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 such as the light rail train, the groundborne noise is masked by the normal airborne noise radiated from the transit vehicle and the rails.

Table 2-4 presents typical vibration levels from rail and non-rail sources, as well as the human and structural 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 the following:

- It is rare that groundborne vibration from transit 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 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 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 (FTA 2018).

Table 2-4. Typical Vibration Level in Decibels and Human/Structural Responses

Vibration Level in VdB	Description of Typical Sources 50 Feet from Source and Human/Structural Response
Below 60 VdB	Typical background vibration levels.
60 to 70 VdB	Light rail transit on a normal track; bus or truck on a smooth roadway. Approximate threshold of human perception and limit for vibration-sensitive equipment.
70 to 80 VdB	Light rail transit near a crossover; bus or truck over pothole. Residential annoyance from infrequent events (e.g., commuter trains), residential annoyance from occasional events, and residential annoyance from frequent events (e.g., light rail transit).
80 to 90 VdB	Bulldozers and other heavy tracked vehicles and freight trains. The typical human response would be difficulty with tasks such as reading a computer screen.
90 to 100 VdB	Blasting from construction projects. This is the threshold for minor cosmetic damage.

Source: Adapted from FTA 2018.

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 method used to evaluate frequency components of acoustic 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 (FTA 2018).

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3 NOISE AND VIBRATION IMPACT CRITERIA

This section summarizes the noise and vibration criteria used to evaluate the operations and construction of the project. Criteria from the FTA, Federal Highway Administration, Washington State Department of Transportation (WSDOT) and the City of Seattle are included and discussed as required for this environmental analysis.

3.1 Noise Criteria

The operation of a light rail system can cause noise that becomes a public concern. Noise impacts can be caused by either transit operations (e.g., light rail operational noise, warning bells, and ancillary facilities) or changes in traffic noise exposure. The major noise source for the project would be noise from Link light rail operations, as well as some additional noise from stations. An increase in traffic noise exposure could result from the development of new or extended roadways in station areas or from the removal of buildings, walls, or berms that currently provide acoustical shielding from traffic noise.

Noise from project-related ancillary facilities can also be a source of noise; these would include maintenance and cleaning facilities, power substations, park-and-rides, and tunnel exhaust fan systems. The maintenance and cleaning facilities for operations of the project will be at the existing Operations and Maintenance Facility Central. No park-and-rides are proposed as part of this project; therefore, no noise analysis for park-and-rides was needed. Substations and tunnel exhaust fans are enclosed in buildings with acoustically treated ventilation systems and are designed to maintain noise levels well below any applicable state or local noise criteria.

There are several different noise impact criteria applicable to the project. Criteria from the FTA, Federal Highway Administration, WSDOT, and the City of Seattle were all reviewed and applied as appropriate to this analysis. This section summarizes those criteria and defines the project noise impact criteria applicable to the project.

3.1.1 Transit Noise Criteria

Noise impacts for the project are determined based on the criteria defined in the FTA Guidance Manual (FTA 2018). The FTA noise impact criteria are founded on well-documented research on community reaction to noise and are based on changes in noise exposure rated using a sliding scale. Although more transit noise is allowed in neighborhoods with high levels of existing noise, as existing noise levels increase, smaller increases in total noise exposure are allowed than in areas with lower existing noise levels. The FTA noise impact criteria group noise-sensitive land uses into the following three categories:

- **Category 1**: Tracts of land where quiet is an essential element in their intended purpose. This category includes lands set aside for serenity and quiet and such land uses as outdoor amphitheaters and concert pavilions, as well as National Historic Landmarks with significant outdoor use. Also included in this category are recording studios and concert halls.
- **Category 2**: Residences and buildings where people normally sleep. This category includes homes, hospitals, and hotels where a nighttime sensitivity to noise is assumed to be of utmost importance.

- **Category 3**: Institutional land uses with primarily daytime and evening use. This category includes schools, libraries, theaters, and places of worship where it is important to avoid interference with such activities as speech, meditation, and concentration on reading material. Places for meditation or study associated with cemeteries, monuments, museums, campgrounds, and recreational facilities are also considered to be in this category. Certain historical sites and parks are also included, but their sensitivity to noise must be related to their defining characteristics, and generally parks with active recreational facilities are not considered noise-sensitive.

Ldn is used to characterize noise exposure for residential areas (Category 2). For other noise-sensitive land uses, such as outdoor amphitheaters and school buildings (Categories 1 and 3), the maximum 1-hour Leq during the facility's operating period is used.

The two levels of impact included in the FTA criteria (moderate and severe) are as follows:

- **Moderate Impact**: In this range of noise impact, the change in the cumulative noise level is noticeable to most people but may not be sufficient to cause strong, adverse reactions from the community. In this transitional area, other project-specific factors must be considered to determine the magnitude of the impact and the need for mitigation. These factors include the existing level, the projected level of increase over existing noise levels, the types and numbers of noise-sensitive land uses affected, the noise sensitivity of the properties, the effectiveness of the mitigation measures, community views, and the cost of mitigating noise to more acceptable levels.
- **Severe Impact**: Project-generated noise in the severe impact range can be expected to cause a large percentage of people to be highly annoyed by the new noise and represents the most compelling need for mitigation. Noise mitigation will normally be specified for severe impact areas unless there are truly extenuating circumstances that prevent mitigation.

The FTA noise impact criteria for Category 2 and Category 3 land uses are summarized in Tables 3-1 and 3-2, which show the existing noise exposure and the allowable noise exposure from a transit project that would cause either moderate or severe impact. The future noise exposure would be the combination of the existing noise exposure and the additional noise exposure caused by the light rail project. As existing noise exposure increases, an increasingly smaller increase in noise is permitted before an impact occurs.

Given the complex nature of these criteria, an example of the application of the criteria can be helpful in understanding how impacts are identified. For example, a residential land use (FTA Category 2) with an existing Ldn of 65 dBA would have no impact if noise from light rail operations were below 61 dBA Ldn, a moderate impact if the light rail noise were between 61 and 66 dBA, and a severe impact if light rail noise were above 66 dBA (Table 3-1). This example shows how the light rail noise level could be *lower* than the *existing* noise levels, and still result in a noise impact. The example also demonstrates how the FTA criteria help to prevent increasing noise levels in areas that already have high levels of background noise. Furthermore, using the information from Table 2-3 (Decibel Addition Approximations), if the light rail operations were, for example, 62 dBA Ldn, the total future noise (existing 65 dBA Ldn plus the light rail's 62 dBA Ldn) would be approximately 67 dBA Ldn, or a 2-dB increase, which is not typically perceptible to an average person but would be an impact under FTA criteria.

The FTA Guidance Manual provides details on how parks are analyzed for noise. The FTA assumes that parks are a special case, and how they are used and where they are located should be considered when considering whether or not a particular park (or an area in a park) is considered noise-sensitive. Parks that are used for active outdoor recreation are typically not considered noise-sensitive. This includes parks with baseball diamonds, soccer fields, basketball courts, football fields, and other active recreation areas.

Table 3-1. FTA Transit Project Noise Impact Criteria for Category 1 and 2 Sites

Existing Noise Exposure Ldn or Leq (dBA) [a]	Transit Noise Level for No Noise Impact	Transit Noise Level for a Moderate Noise Impact	Transit Noise Level for a Severe Noise Impact
<43	<Ambient +10	Ambient +10 to 15	>Ambient +15
43	<52	52 to 58	>58
44	<52	52 to 58	>58
45	<52	52 to 58	>58
46	<53	53 to 59	>59
47	<53	53 to 59	>59
48	<53	53 to 59	>59
49	<54	54 to 59	>59
50	<54	54 to 59	>59
51	<54	54 to 60	>60
52	<55	55 to 60	>60
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62	<59	59 to 64	>64
63	<60	60 to 65	>65
64	<61	61 to 65	>65
65	<61	61 to 66	>66
66	<62	62 to 67	>67
67	<63	63 to 67	>67
68	<63	63 to 68	>68
69	<64	64 to 69	>69
70	<65	65 to 69	>69
71	<66	66 to 70	>70
72	<66	66 to 71	>71
73	<66	66 to 71	>71
74	<66	66 to 72	>72
75	<66	66 to 73	>73
76	<66	66 to 74	>74
77	<66	66 to 74	>74
>77	<66	66 to 75	>75

Source: FTA 2018.

[a] The Ldn is used for FTA Category 2 sites, including residential land use and other sites where people sleep, and the peak hour Leq is used for Category 1 sites.

Table 3-2. FTA Transit Project Noise Impact Criteria for Category 3 Sites

Existing Noise Exposure Leq (dBA)	Transit Noise Level for No Noise Impact	Transit Noise Level for a Moderate Noise Impact	Transit Noise Level for a Severe Noise Impact
<43	<Ambient +15	Ambient +15 to 20	>Ambient +20
43	<57	57 to 63	>63
44	<57	57 to 63	>63
45	<57	57 to 63	>63
46	<58	58 to 64	>64
47	<58	58 to 64	>64
48	<58	58 to 64	>64
49	<59	59 to 64	>64
50	<59	59 to 64	>64
51	<59	59 to 65	>65
52	<60	60 to 65	>65
53	<60	60 to 65	>65
54	<60	60 to 66	>66
55	<61	61 to 66	>66
56	<61	61 to 67	>67
57	<62	62 to 67	>67
58	<62	62 to 67	>67
59	<63	63 to 68	>68
60	<63	63 to 68	>68
61	<64	64 to 69	>69
62	<64	64 to 69	>69
63	<65	65 to 70	>70
64	<66	66 to 70	>70
65	<66	66 to 71	>71
66	<67	67 to 72	>72
67	<68	68 to 72	>72
68	<68	68 to 73	>73
69	<69	69 to 74	>74
70	<70	70 to 74	>74
71	<71	71 to 75	>75
72	<71	71 to 76	>76
73	<71	71 to 76	>76
74	<71	71 to 77	>77
75	<71	71 to 78	>78
76	<71	71 to 79	>79
77	<71	71 to 79	>79
>77	<71	71 to 80	>80

Source: FTA 2018.

Parks that are noise-sensitive would be those where quiet is an essential element in their intended purpose or places where it is important to avoid interference with activities such as speech, meditation, and reading. The existing noise levels at a park can provide some indication of the sensitivity of its use. All parks along the West Seattle Link Extension corridor were evaluated for consideration under the FTA criteria and, based on the park locations and existing noise levels, only those parks in quiet areas without active sports met the requirements for noise sensitivity under the FTA Category 3 criteria. Noise-sensitive parks include the Longfellow Creek Natural Area in the Delridge Segment. All other parks are in areas with high existing noise levels or are active sports fields. Additional information on parks as related to noise and vibration is provided in Chapter 5, Affected Environment.

3.1.2 Traffic Noise Criteria

Criteria for traffic noise impacts are from the Federal Highway Administration Procedures for Abatement of Highway Traffic Noise and Construction Noise, Code of Federal Regulations Title 23, Subchapter H, Section 772 (1982). A traffic noise impact occurs if predicted traffic noise levels approach the criteria levels for specific land use categories or substantially exceed existing noise levels (e.g., a 10-dBA increase). These levels are defined as noise abatement criteria and are based on hourly Leq levels for the peak hour of traffic noise. The Federal Highway Administration has land use categories that are similar to the ones used by the FTA, although the Federal Highway Administration categories use letters instead of numbers. The land uses of greatest concern in the project corridor are Federal Highway Administration Type B and Type C land uses, which include residences, playgrounds, active sports areas, parks, schools, places of worship, libraries, and hospitals. Hotels, motels, offices, restaurants and bars, and other developed lands are included in Federal Highway Administration Type E land use category and have a higher impact level than Federal Highway Administration Types B and C land use. The noise abatement criterion used to determine impacts on Federal Highway Administration Types B and C land use is 67 dBA Leq, and for Type E land use the criteria is 72 dBA Leq. Under WSDOT policy, a traffic noise impact occurs if predicted noise levels are within 1 dB of the noise abatement criteria. Therefore, an impact on Type B and Type C land uses would occur at 66 dBA, and at 71 dBA Leq for Type E land use.

WSDOT is responsible for implementing the Federal Highway Administration regulations in Washington state. Under Federal Highway Administration and WSDOT regulations, any highway project receiving federal funds must have a noise analysis if it includes elements including new roadway or highway, substantial alteration of the alignment of an existing roadway or highway, or adding new capacity to an existing roadway or highway. The removal of physical shielding (e.g., building or topographical conditions), which provide traffic noise attenuation, also counts as an alteration of the alignment. There are some limited locations under some alternatives where project-related displacement may warrant a traffic noise study. The impact assessments for those areas are presented in Chapter 6, Impact Assessment.

3.1.3 Construction Noise Criteria

Project construction would take place in the city of Seattle. The City has its own municipal noise ordinance that would be applicable to the project. Noise impacts are assessed using the City of Seattle noise ordinance, which has more stringent criteria than the FTA criteria.

The maximum permissible sound levels from construction activities are governed by the Seattle Municipal Code, where Section 25.08 specifies permissible sound limits within Seattle. Seattle Municipal Code 25.08.410 sets forth separate sound limits for residential, commercial, and industrial districts. These districts, defined in Seattle Municipal Code 25.08.100, are based on the zoning of the affected properties. While districts are based on zoning, the two are not equivalent. For example, Neighborhood Commercial-1 is a commercial zone, but is considered a residential district. Table 3-3 shows the exterior sound level limits applicable to each district.

Table 3-3. City of Seattle Exterior Sound Level Limits

District of Sound Source	Residential Receiving Districts Leq (Lmax) (in dBA)	Commercial Receiving Districts Leq (Lmax) (in dBA)	Industrial Receiving Districts Leq (Lmax) (in dBA)
Residential	55 (70)	57 (72)	60 (75)
Commercial	57 (72)	60 (75)	65 (80)
Industrial	60 (75)	65 (80)	70 (85)

Source: Seattle Municipal Code 25.08.410, Exterior Sound Level Limits.

Notes:

Measurement time is 1 minute for a constant sound source and 1 hour for a varying sound source.

During measurement intervals, maximum sound level (Lmax) may exceed Leq limits by no more than 15 dBA.

The exterior sound level limits shown in Table 3-3 may be modified under certain circumstances, as outlined in Seattle Municipal Code 25.08.420. These modifications are for certain times of the day, classification of receiving properties, and type of sound generated. These modifications to the exterior sound level limits include the following reductions:

- 10 dB at receiving properties within residential districts during the nighttime hours of 10 p.m. and 7 a.m. on weekdays, 10 p.m. and 9 a.m. on weekends, and 10 p.m. and 9 a.m. on legal holidays
- 5 dB for sources that carry a pure tone component
- 5 dB for impulsive sources not measured with an impulse sound level meter

These reductions are cumulative and independent of one another. Therefore, the permissible nighttime exterior sound level in a residential district from an impulsive, tonal source would be 20 dB less than the exterior sound level described in Table 3-3.

Modifications to the permissible exterior sound level limits shown in Table 3-3 are allowed for construction activities. Daytime, non-impact construction activities are subject to Seattle Municipal Code 25.08.425. For public projects such as Sound Transit projects, modifications are permitted to the exterior sound level limits in all zones between 7 a.m. and 10 p.m. on weekdays and between 9 a.m. and 10 p.m. on weekends and legal holidays. The modifications allowed under Seattle Municipal Code 25.08.425 include the following increases during daytime hours:

- 25-dB increase for equipment on construction sites, including but not limited to crawlers, tractors, dozers, rotary drills and augers, loaders, power shovels, cranes, derricks, graders, off-highway trucks, ditchers, trenchers, compactors, compressors, and pneumatic-powered equipment
- 20-dB increase for portable powered equipment used in temporary locations in support of construction activities in any zone, maintenance activities on commercial property, or used in maintenance of public facilities, including but not limited to chainsaws, log chippers, lawn and garden maintenance equipment, and powered hand tools

- 15-dB increase for powered equipment used in temporary or periodic maintenance or repair of the grounds and appurtenances of residential property, including but not limited to lawnmowers, powered hand tools, snow-removal equipment, and composters

The resulting exterior sound level limits from construction activities are measured at the adjacent property line or 50 feet from the equipment generating the sound, whichever is greater. The resulting daytime construction sound limits are listed in Table 3-4.

Table 3-4. City of Seattle Exterior Daytime Construction Sound Level Limits

District of Sound Source	Residential Receiving Districts Leq (Lmax) (in dBA)	Commercial Receiving Districts Leq (Lmax) (in dBA)	Industrial Receiving Districts Leq (Lmax) (in dBA)
Residential	80 (95)	82 (97)	85 (100)
Commercial	82 (97)	85 (100)	90 (105)
Industrial	85 (100)	90 (105)	95 (110)

Source: Seattle Municipal Code 25.08.410 and Seattle Municipal Code 25.08.425.

Notes:

Measurement time is 1 minute for a constant sound source and 1 hour for a varying sound source.

During measurement intervals Lmax may exceed Leq limits by no more than 15 dBA.

Seattle Municipal Code 25.08.425 also includes modifications to the permissible exterior sound level limits for impact types of construction equipment, including equipment that create impulse sound or impact sound, or are used as impact equipment. Examples of this type of equipment are pavement breakers, pile drivers, jackhammers, and sandblasting tools. Impact construction equipment can exceed the exterior sound level limits in any 1-hour period between 8 a.m. and 5 p.m. on weekdays and 9 a.m. and 5 p.m. on weekends and legal holidays. However, sound levels associated with impact construction equipment are not allowed to exceed the values set forth in Table 3-5. These values are defined at the adjacent property line or 50 feet from the equipment, whichever is greater.

Table 3-5. City of Seattle Daytime Impact Construction Sound Level Limits

Activity During 1-Hour Period	Leq (dBA)
Continuous	90
30 minutes	93
15 minutes	96
7.5 minutes	99

Source: Seattle Municipal Code 25.08.425.

Note: Standard of measurement is a 1-hour Leq. Leq may be measured for times not less than 1 minute to project an hourly Leq.

In addition to providing modifications for exterior sound levels during construction, Seattle Municipal Code 25.08.425 also defines permissible limits for sound levels measured inside a commercial building adjacent to construction activities. Specifically, construction or maintenance equipment that exceeds the exterior sound level limits outlined in Table 3-4 when measured from the interior of buildings in a commercial district is prohibited between the hours of 8 a.m. and 5 p.m. Seattle Municipal Code 25.08.425 states that “interior sound levels shall be measured only after every reasonable effort, including but not limited to closing windows and doors, is taken to reduce the impact of the exterior construction noise.”

Typically, noise reduction due to the barrier effect of the building (e.g., noise reduction from the exterior to interior of a building assuming all doors and windows are closed) is approximately 25 dB. This is equivalent to the code modification allowed for construction noise (25 dB). Those interior limits are usually satisfied when work complies with daytime exterior construction noise limits and is farther than 50 feet from a commercial building.

3.2 Vibration Criteria

Rail transit can result in vibration that results in perceptible building vibration, rattle noises, and reradiated noise (groundborne noise). Vibration caused by light rail operations is typically well below what would cause even minor cosmetic damage to buildings. Therefore, the criteria for building vibration caused by transit operations are primarily concerned with potential annoyance of building occupants. Vibration caused by construction equipment and activities is typically evaluated for potential damage to nearby buildings rather than annoyance because it is temporary.

3.2.1 Transit Vibration Criteria

The FTA vibration impact criteria are based on the maximum indoor vibration level as a train passes. There are no impact criteria for outdoor spaces such as parks. The FTA vibration thresholds do not specifically account for existing vibration because it is very rare that even substantial volumes of vehicular traffic including trucks and buses would generate perceptible ground vibration unless there are irregularities in the roadway surface such as potholes or wide expansion joints. The FTA Guidance Manual (2018) recommends that where there are existing rail lines, existing vibration conditions should be considered when determining vibration impact criteria for a new transit project. For a discussion of locations where there are existing trains or transit vehicles in the corridor, refer to Section 5.3.1, Ambient Vibration Survey (Representative Sites).

Like noise, the sensitivity to vibration varies by land use type, and the criteria represent these sensitivities. Sensitive land use categories for vibration assessment are presented in Table 3-6 in order of sensitivity.

Table 3-6. Land Use Categories for Vibration Assessment

Land Use Category	Land Use Type	Description of Land Use Category
Not applicable	Special Buildings	This category includes special-use facilities that are very sensitive to vibration and groundborne noise that are not included in the categories below and require special consideration. Examples of these facilities include concert halls, television and recording studios, and theaters.
1	High Sensitivity	This category includes buildings where vibration levels, including those below the threshold of human annoyance, would interfere with operations within the building. Examples include buildings where vibration-sensitive research and manufacturing equipment is conducted, hospitals with vibration-sensitive equipment, and universities conducting physical research operations. The building's degree of sensitivity to vibration is dependent on the specific equipment that will be affected by the vibration.
2	Residential	This category includes all residential land use and buildings where people normally sleep, such as hotels and hospitals. Transit-generated groundborne vibration and noise from subways or surface running trains are considered to have a similar effect on receivers.
3	Institutional	This category includes institutions and offices that have vibration-sensitive equipment and have potential for activity interference such as schools, places of worship, and doctors' offices. Commercial or industrial locations including office buildings are not included in this category unless there is vibration-sensitive activity or equipment within the building. As with noise, the use of the building determines the vibration sensitivity.

Source: FTA 2018.

The FTA Guidance Manual (2018) provides two sets of criteria: one based on the overall vibration velocity level for use in a general vibration impact assessment 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. This analysis applied the detailed vibration assessment criteria. The thresholds for use with the detailed vibration assessments are shown on Figure 3-1 and Table 3-7. For the detailed assessment, the predicted vibration levels in terms of the 1/3-octave band spectra are compared to the curves shown on Figure 3-1 to determine whether there is impact and the frequency range over which vibration mitigation should be evaluated. If the predicted vibration levels are below the curves on Figure 3-1 over the entire spectra, no impact is predicted.

Table 3-7 gives a description of the land uses that correspond to each of the vibration criteria (V.C.) curves on Figure 3-1, which are designated V.C.-A through V.C.-E. The curves apply to vibration-sensitive equipment, such as microscopes or magnetic resonance imaging machines. The Residential (Day) curve is applied to institutional land uses (Category 3) such as places of worship and schools, and the Residential (Night) curve is applied to residential land uses (Category 2).

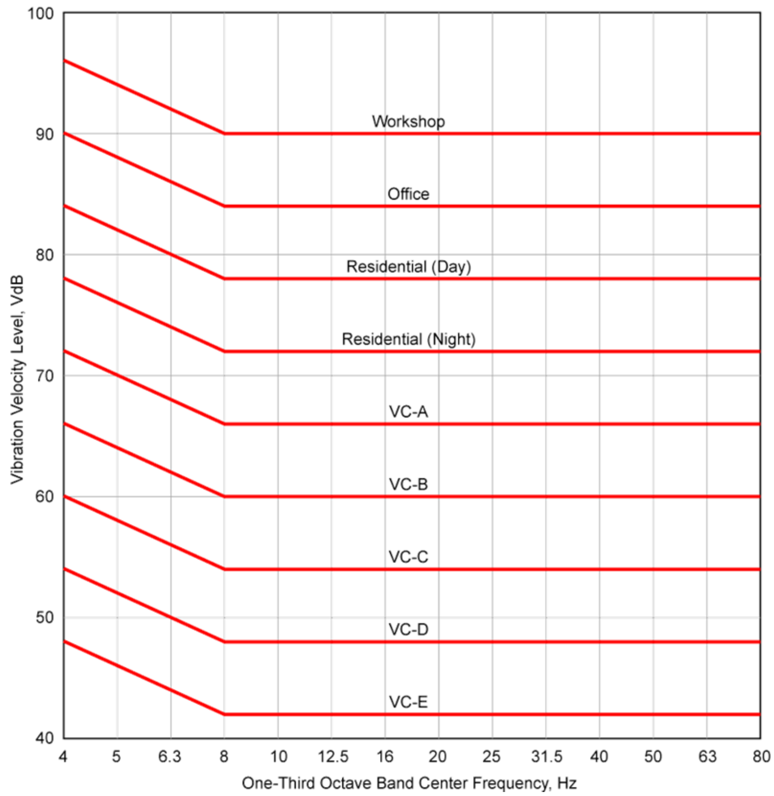
Table 3-7. Interpretation of FTA Vibration Criteria for Detailed Analysis

Criterion Curve	Maximum Vibration Velocity (VdB) [a]	Description of Use
Workshop	90	Distinctly detectable vibration; appropriate to workshops and non-sensitive areas
Office	84	Detectable vibration; appropriate to offices and non-sensitive areas
Residential day	78	Barely detectable vibration; adequate for computer equipment and low-power optical microscopes (up to 20 times power)
Residential night, operating rooms and sensitive hospital equipment	72	Vibration not detectable, but groundborne noise might be audible inside quiet rooms; suitable for medium-power optical microscopes (100 times power) and other equipment of low sensitivity
V.C.-A	66	Adequate for medium- to high-power optical microscopes (400 times power), microbalances, optical balances, and similar specialized equipment
V.C.-B	60	Adequate for high-power optical microscopes (1,000 times power) and inspection and lithography equipment up to 3 micron-line widths
V.C.-C	54	Appropriate for most lithography and inspection equipment to 1-micron detail size
V.C.-D	48	Suitable in most instances for the most demanding equipment, including electron microscopes operating to the limits of their capability
V.C.-E	42	The most demanding criterion for extremely vibration-sensitive equipment

Source: FTA 2018.

[a] As measured in 1/3-octave bands of frequency over the frequency range of 8 to 80 hertz.

Figure 3-1. FTA Criteria for Detailed Vibration Assessment



Source: FTA 2018.

3.2.2 Groundborne Noise Criteria

Some buildings, such as concert halls, recording studios, and theaters, can be particularly sensitive to groundborne noise. Because of their sensitivity, these buildings usually warrant special attention during the impact assessment. Table 3-8 gives criteria for acceptable levels of groundborne vibration and groundborne noise for various types of special buildings.

Table 3-8. Groundborne Vibration and Noise Impact Criteria for Special Buildings

Type of Building or Room [a]	Groundborne Vibration Impact Levels for Frequent Events (VdB) [b]	Groundborne Noise Impact Levels for Frequent Events (dBA) [b]
Concert Halls	65 VdB	25 dBA
Television Studios	65 VdB	25 dBA
Recording Studios	65 VdB	25 dBA
Auditoriums	72 VdB	30 dBA
Theaters	72 VdB	35 dBA

Source: FTA 2018.

[a] If the building will rarely be occupied when trains are operating, then there is no need to consider impact. As an example, consider locating a commuter rail line next to a concert hall; if no commuter trains will operate after 7 p.m., then trains would rarely interfere with the use of the hall.

[b] "Frequent events" are defined as more than 70 vibration events per day; most transit projects fall into this category.

Table 3-9 presents the groundborne noise impact criteria for three different land use types. Category 1 land uses are buildings where low ambient vibrations are essential for interior operations, such as laboratories. These spaces are generally not sensitive to groundborne noise and therefore no groundborne noise criteria is applicable to these spaces. Limits for spaces particularly sensitive to groundborne noise are covered in Table 3-8.

Table 3-9. Groundborne Noise Impact Criteria for Frequent Events

Land Use Category	Groundborne Noise Impact for Frequent Events (decibels re 20 micropascals) [a]
Category 1: Buildings where low ambient vibration is essential for interior operations	Not applicable [b]
Category 2: Residences and buildings where people normally sleep	35 dBA
Category 3: Institutional land uses with primarily daytime use	40 dBA

Source: FTA 2018.

[a] "Frequent events" are defined as more than 70 vibration events of the same source per day; most rapid transit projects fall into this category.

[b] Vibration-sensitive equipment is generally not sensitive to groundborne noise.

3.2.3 Construction Vibration Criteria

Construction vibration was assessed for both potential damage to structures and human annoyance. For potential vibration effects during construction, the FTA's recommended criteria on vibration levels is applied because there are no state, county, or municipal vibration regulations. The parameter normally used to assess potential construction vibration effects to structures is peak particle velocity, which is the maximum velocity recorded during a particular event, such as from a jackhammer. The FTA's recommended limits for construction vibration for four building categories are as follows:

- Reinforced concrete, steel, or timber: 0.5 inch per second peak particle velocity
- Engineered concrete and masonry: 0.3 inch per second peak particle velocity
- Nonengineered timber and masonry buildings: 0.2 inch per second peak particle velocity
- Buildings extremely susceptible to vibration damage: 0.12 inch per second peak particle velocity

Annoyance from groundborne noise and vibration is generally not assessed for construction activities because they are short-term in duration. However, potential interference with sensitive activities at Category 1 or Special Building land uses from groundborne noise and vibration due to construction are evaluated applying the criteria for operations in Tables 3-8 and 3-9. At Category 1 and Special Building land uses, groundborne noise and vibration from even short-term construction activities may interfere with sensitive research processes or planned performance or recording events that would disrupt the normal operations at those facilities. Potential annoyance at Category 2 (residential) and Category 3 (institutional) land uses were evaluated for reference using the operational criteria but were not used to identify potential construction vibration impacts. The exception is groundborne noise and vibration from tunnel muck and support trains, which are evaluated to meet the FTA criteria for operations based on annoyance because the tunnel support trains may run continuously over several years.

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4 NOISE AND VIBRATION IMPACT ANALYSIS ASSUMPTIONS AND METHODS

This section summarizes the assumptions and methods used for the noise and vibration analysis. In order to evaluate noise and vibration resulting from a transit project, identifying and characterizing the various project elements that could generate or potentially affect noise or vibration levels is essential. Key elements and sources pertaining to noise and vibration levels for the project are described in the following sections.

4.1 Noise Assumptions and Methods

This section summarizes the approach used to identify and characterize noise sources and predict future noise levels for potential sources of community impacts related to the West Seattle Link Extension. Project elements potentially influencing noise include light rail operation, track types and configuration, changes in traffic related to the project, and construction activities. Noise impacts from the operation and construction of the Build Alternatives were determined through noise and vibration modeling using FTA methods.

4.1.1 Operational Noise Elements

The plan and profile of the new light rail alignment, including the locations of special track work such as crossovers, and typical speeds were provided by the project design engineers. The plan and profile drawings used are included in Appendix J, Conceptual Design Drawings, of the West Seattle Link Extension Final EIS. The design information provided includes the elevation of the guideway, type of track (ballast-and-tie, embedded, and direct-fixation) and the location and design of the station alternatives.

4.1.1.1 Light Rail Operational and Maintenance Measures

This section describes the assessment approach for noise related to operating the light rail system. This includes noise from light rail operations, ancillary facilities, and wheel squeal. Sound Transit employs several operational measures to maintain low noise and vibration levels for its light rail trains. Table 4-1 lists operational and maintenance measures that Sound Transit performs on a regular basis and the benefit that each measure provides.

Table 4-1. System-wide Light Rail Operational and Maintenance Measures

Operational Measure	System Benefit
Rail grinding, maintenance, and replacement	As rails wear, both noise and vibration levels from light rail operations can increase. By grinding or replacing worn rails or correcting improper track alignment, noise and vibration levels will remain at the projected levels.
Wheel truing and replacement	Wheel truing is a method of grinding down flat spots (commonly called wheel flats) on the vehicle wheels. Flat spots occur primarily because of hard braking. When flat spots occur, they can cause increases in both the noise and vibration levels produced by the light rail vehicles.
Vehicle maintenance	Vehicle maintenance includes performing scheduled and general maintenance on items such as air conditioning units, bearings, wheel skirts, and other mechanical units on the light rail vehicles. Keeping the mechanical systems on the light rail vehicles in top condition will also help to maintain the projected levels of noise and vibration.
Operator training	Operators will be trained to operate light rail vehicles at the speeds given in the operation plan that was used for the analysis and to avoid hard braking, which can cause wheel flats and may also damage the track. Furthermore, by training operators to identify potential wheel flats and other mechanical problems with the light rail trains, proper maintenance can be performed in a timely manner.

4.1.1.2 Reference Light Rail Noise Levels

Sound Transit modeled noise from light rail operations using the methods described in the FTA Guidance Manual (FTA 2018). Input to the model included measured reference noise levels for the new light rail vehicles that are currently being used on the existing Link light rail system. Reference measurements for light rail operations were taken from the *2019 Reference Noise and Vibration Levels for Link Light Rail Projects* (Sound Transit 2019). The measured reference noise levels include measured levels in 5-mile-per-hour increments for ballast-and-tie track, direct-fixation track, and embedded track.

The speeds used in this analysis are the track design speeds. The light rail speed is limited by speed limited curves and reduced speed when accessing at stations. The speeds used in the analysis may be higher than actual speeds and assure a conservative noise impact analysis. More detailed information on how all this information is used to predict operational noise levels are provided in Section 4.1.2, Operational Noise Prediction Methods.

4.1.1.3 Crossovers and Special Track Work

Track crossovers are mechanical devices that enable light rail cars to be guided from one track to another at a junction point. Crossovers have a gap in the rails that is necessary for the flange of the light rail wheels to pass through at the location where the two tracks cross. As a wheel passes through the gap, there are increased noise and vibration levels. A frog is a rail-crossing structure that allows the train to cross over to another track or continue moving on the same track. A gap is provided on top of the frog so that vehicle wheels can pass regardless of which track is in use. According to the FTA Guidance Manual and measurements of the Link light rail system, standard frogs can increase noise levels by as much as 5 to 10 dB.

4.1.1.4 Light Rail Warning Bells

Consistent with Sound Transit operating rules, train-mounted bells would be sounded twice as a train enters a station and twice when the train leaves the station. The bells produce a maximum noise level of 80 dBA at 50 feet between 6 a.m. and 10 p.m. and are reduced to 72 dBA Lmax between 10 p.m. and 6 a.m. Sound Transit measured and validated train-mounted bells on light rail cars in October 2009, with several supplemental measurements in 2011 and 2012.

4.1.1.5 Operations Plan

The operations plan for this analysis reflects a future build-out of the regional light rail system established by the Sound Transit 3 Plan (Sound Transit 2016). This assumes light rail service is operating to north to Everett, south to Tacoma, and east to Downtown Redmond. Under this maximized future operational plan, the light rail trains would operate with four passenger cars during all periods of service.

Train frequencies are established based on ridership demand and other service standards. Table 4-2 shows the new service schedule for weekdays. Weekend and holiday service levels are based on early and late service levels, as shown in the table.

Table 4-2. Weekday Service Periods for Year 2042

Service Period	Time Period	Service Level	Train Frequency (minutes)
Early morning	5 a.m. to 6 a.m.	Early	10
Morning peak	6 a.m. to 8:30 a.m.	Peak	6
Midday	8:30 a.m. to 3 p.m.	Base	10
Afternoon peak	3 p.m. to 6:30 p.m.	Peak	6
Evening	6:30 p.m. to 10 p.m.	Base	10
Late Evening	10 p.m. to 1 a.m.	Late	15

Vehicle, track, and systems maintenance occurs between approximately 1 a.m. and 5 a.m. daily, outside of normal hours of light rail service. Based on preliminary operating plans, approximately two trains may be deployed between 4:30 and 5 a.m. to stage trains for the beginning of morning service at project stations. Similarly, about two trains may operate between approximately 1 and 1:30 a.m. along the West Seattle Link Extension as they return to the operations and maintenance facilities at the close of service each day.

4.1.1.6 Wheel Squeal and Wheel-flanging Noise

Wheel squeal is caused by the oscillation of the wheel against the rail on curved sections of rail. Sound Transit measured wheel squeal noise levels at several different locations along the Link light rail corridor and used these measurements as reference data. Based on these measurements, curves with radii of less than 600 feet and potentially up to 1,250 feet can produce maximum wheel squeal noise levels of 80 dBA to 90 dBA at 50 feet.

Research into methods of reducing wheel squeal noise, including using non-oil-based lubricants (such as water) and friction modifiers, has found such methods effectively reduce or eliminate wheel squeal. The lubricants can be applied by personnel working trackside or by an automated applicator. As provided in the Sound Transit *Design Criteria Manual, Revision 5* (Sound Transit 2021), potential for wheel squeal shall be identified. Locations where tight-radius curves of 600 feet or less are near noise-sensitive receivers shall include wheel squeal mitigation measures in the project design. In addition, provisions for wayside lubrication shall be incorporated in the project design at all curves up to a 1,250-foot radius near commercial or residential areas. If audible wheel squeal or flanging noise are present on curve radii of 601 feet to 1,250 feet during pre-revenue service, then mitigation such as wayside lubrication shall be applied to the rail gauge face and wheel flange. Because the noise level from wheel squeal varies greatly depending on curve radius, train speed, and track type, modeling of squeal is not normally performed. However, all curves with radii up to 1,250 feet are identified in the impact analysis in Chapter 6, Impact Assessment.

4.1.1.7 Light Rail Track Types

The track installation method can have an effect on noise levels emitted from light rail operations. First, all tracks on the Link light rail systems are continuously welded. Unlike freight rail tracks, which are butted, leaving a gap between tow rails that can increase noise and vibration levels, Sound Transit's welded rails provide a continuous smooth surface, reducing noise and vibration and improving the ride quality for patrons.

The overall track installation is generally performed using one of three methods: ballasted track, direct-fixation track or embedded track. Ballasted track is similar to freight rail tracks, with the track installed on concrete ties that are installed on top of the ballast, a crushed rock surface. Ballasted track is used mainly for at-grade guideways, and the ballast can absorb some of the noise making this the quietest of the three track installation methods. Direct-fixation track is guideway where the rails are installed with fasteners directly on a concrete plinth. This is also the method used on most all elevated structures and in tunnels. Due to the hard-reflective plinth surface, this method of track installation can increase the overall noise from the system by up to 3 dB for at-grade systems and 4 dB for elevated systems. The added noise from the elevated system is due, in part, to noise radiating directly from the structure.

The final type, embedded track, is usually a type of direct-fixation track embedded in a concrete slab or paved over to allow motor vehicles to drive over the tracks. This installation method is reserved for at-grade tracks with vehicles overcrossing. The only locations with embedded track in the project area are at access points for hi-rail vehicles, the service trucks that can operate along the guideway for servicing. Table 4-3 summarizes the different track types and corrections used for the project noise analysis.

Table 4-3. Light Rail Track-type Adjustments

Track Type	Adjustment in Decibels
At-grade ballast-and-tie track (ballast exposed)	0
Elevated structure	+4
Embedded track or retained-fill guideway	+3

Source: FTA 2018.

In some cases, the trackway would be installed in a retained cut, where the trackway is cut into the side of a hill; an example of this is along Pigeon Point in the Duwamish Segment. In these cases, the topographical conditions are included in the analysis and can provide shielding of noise from light rail operations. The level of shielding is calculated based on the relationship between the trackway and the noise-sensitive property. Depending on the depth of the cut and locations of sensitive properties, noise reductions of 0 to 10 dB or more are possible.

4.1.2 Operational Noise Prediction Methods

Noise impacts that would result from the project were determined through the following approach:

- Sound Transit performed a land use survey of potential noise-sensitive receivers near the new light rail alignments. This process involved site visits and use of land use maps and information.
- Sound Transit conducted long-term (multi-day) and short-term (15- to 30-minute) noise monitoring to establish existing noise levels for the potentially affected area. Ambient noise monitoring was taken at 42 locations along the project corridor. The criteria for selecting the monitoring locations included location of potential alignments, land use, existing ambient noise, number of sensitive receivers in the area, and level of expected impact.
- Field noise measurements were used to develop a set of existing ambient sound levels for the noise-sensitive receivers.
- The existing ambient sound levels were also used to determine the noise impact criteria. The FTA criteria for noise impacts are based on the existing noise level and land use.

- Projections of light rail noise levels were made based on track type, train speed, number of passenger cars, and distance of receiver from tracks, with adjustments for shielding and ground attenuation. Adjustments for track crossovers are discussed in Section 4.1.1.3, Crossovers and Special Track Work. Mitigation adjustments based on track type are provided in Section 7.1, Operational Noise Mitigation. Typical noise reductions for sound walls, elevated acoustical walls, and trench situations are shown in Section 7.1. Sound attenuation related to physical shielding from the elevated structure and other existing and planned structures was included in the analysis using acoustical formulas from the FTA Guidance Manual (FTA 2018). Noise related to bells at stations was included in the analysis as described in Section 4.1.1.4, Light Rail Warning Bells.
- Sound Transit evaluated noise projections with respect to the FTA impact thresholds to determine whether a receiver would be affected by light rail operations. Where noise impacts were identified, mitigation recommendations follow Sound Transit's Light Rail Noise and Vibration Mitigation Policy (Sound Transit 2023).
- Measured noise-level reductions from existing noise barriers installed on the elevated guideway and at-grade track along the existing Link Light Rail System and information from the FTA Guidance Manual (2018) were used to assist in the final mitigation predictions.

4.1.3 Traffic Noise Prediction Methods

The potential to create or increase exposure to traffic noise as a result of the transit project must also be considered. As defined in Federal Highway Administration noise abatement policy (2010), changes in the traffic noise environment could occur if the project creates new roadways or alters existing roadways in relation to noise-sensitive properties or changes the pathway for traffic noise by removing or altering barriers (buildings, berms, or walls) that currently provide some level of shielding from traffic noise. These locations are identified and evaluated for potential traffic noise impacts based on existing noise measurements and Federal Highway Administration impact criteria.

4.1.4 Construction Noise Prediction Methods

Potential impacts from construction noise were evaluated using representative sound levels from various types of construction equipment provided in the FTA Guidance Manual (2018). Construction sound levels were generally predicted using the methodology detailed in Section 7 of the FTA Guidance Manual (2018), which analyzes the two loudest pieces of equipment expected for a particular construction activity. Resulting sound levels were compared to codified sound limits within the city of Seattle.

The analysis predicted sound levels from activities expected to produce the highest sound levels, require several months to complete, or require work during nighttime hours. These construction activities include elevated light rail construction, retained-cut construction, tunneling, cut-and-cover station construction, and bridge construction over water crossings.

For Category 1 land uses, computer noise models were used to predict sound levels from construction. Noise models were made using the 3-D computer noise modeling software environment, CadnaA. The CadnaA models use the International Organization for Standardization 9613 Part II algorithms, which account for the effects of distance, topography, and surface reflections on sound levels. Due to variations in sound levels created by construction equipment and the locations of construction equipment, actual sound levels at nearby properties may vary for any specific construction activity.

4.2 Vibration Assumptions and Methods

Both the construction and operation of a light rail system generate vibration that is transmitted through the ground and into nearby buildings. It is rare for the vibration from train operations to be high enough to create a risk of structural damage to buildings. However, it is possible for construction vibration to approach risk thresholds for minor cosmetic damage. Construction and light rail operations both have the potential to generate vibration that may be intrusive to building occupants. The following vibration sources are associated with light rail systems:

- Train operations: Light rail operations can create groundborne vibration that can be intrusive to occupants of buildings close to the tracks. However, light rail operation vibration levels in general are well below the thresholds used to protect sensitive and fragile structures from damage. A key assumption in the vibration predictions is that optimal wheel and rail profiles would be maintained for the system through periodic truing of the wheels and rail grinding.
- Special track work: The wheel impacts at the frogs used at special track work for turnouts and switches increases vibration levels. A frog is a rail-crossing structure at track crossovers that allows the train to cross over to another track or continue moving on the same track.

4.2.1 Operational Vibration Prediction Methods

To predict groundborne vibration associated with the West Seattle Link Extension, the detailed vibration assessment procedure outlined in the FTA Guidance Manual (2018) was followed. This is an empirical model based on testing the vibration propagation characteristics of the soil in the project corridor and measurements of the vibration characteristics of existing Sound Transit light rail vehicles. As is discussed in Section 5.3.2, Vibration Propagation Tests, vibration propagation measurements were performed at surface and below-grade locations throughout the new project corridors.

The result of the vibration propagation tests is the line source transfer mobility, a measure of how efficiently vibration propagates through the soil. The force density level quantifies the vibration forces generated by the train and track. The basic relationship used for the vibration predictions is:

Lv = Force Density Level + Line Source Transfer Mobility + Safety Factor

Where: Lv is the train vibration velocity measured at the ground surface. Force density level is derived by measuring Lv and line source transfer mobility at a site where there are existing light rail vehicle operations. The force density levels used in this analysis are the measured force density level values of the existing Sound Transit Link light rail system (Rajaram 2019). The force density levels depend on speed and track type. The force density levels are available for speeds in increments of 5 miles per hour from 25 miles per hour to 55 miles per hour for ballast-and-tie and direct-fixation track structures. The force density level for the two track structure types at 55 miles per hour is shown on Figure 4-1. The force density levels include a 3-dB safety factor.

Elevated structures typically reduce vibration by about 10 dB relative to at-grade track. For this assessment, an adjustment of -10 dB was applied at all 1/3-octave band center frequencies except at 10 hertz and 12 hertz, as shown on Figure 4-2. This adjustment is based on force density level measurements of a Link aerial structure (Rajaram and Wolf 2014).

Figure 4-1. Force Density Levels at 55 Miles per Hour for Direct-Fixation and Ballast-and-Tie Track Structures

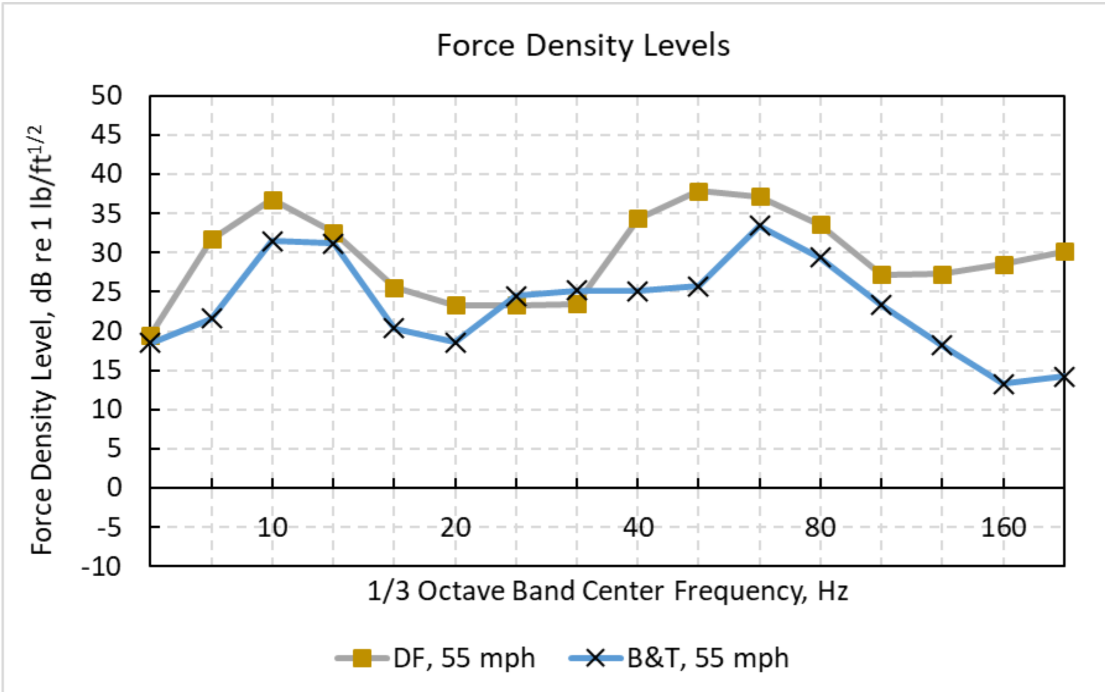
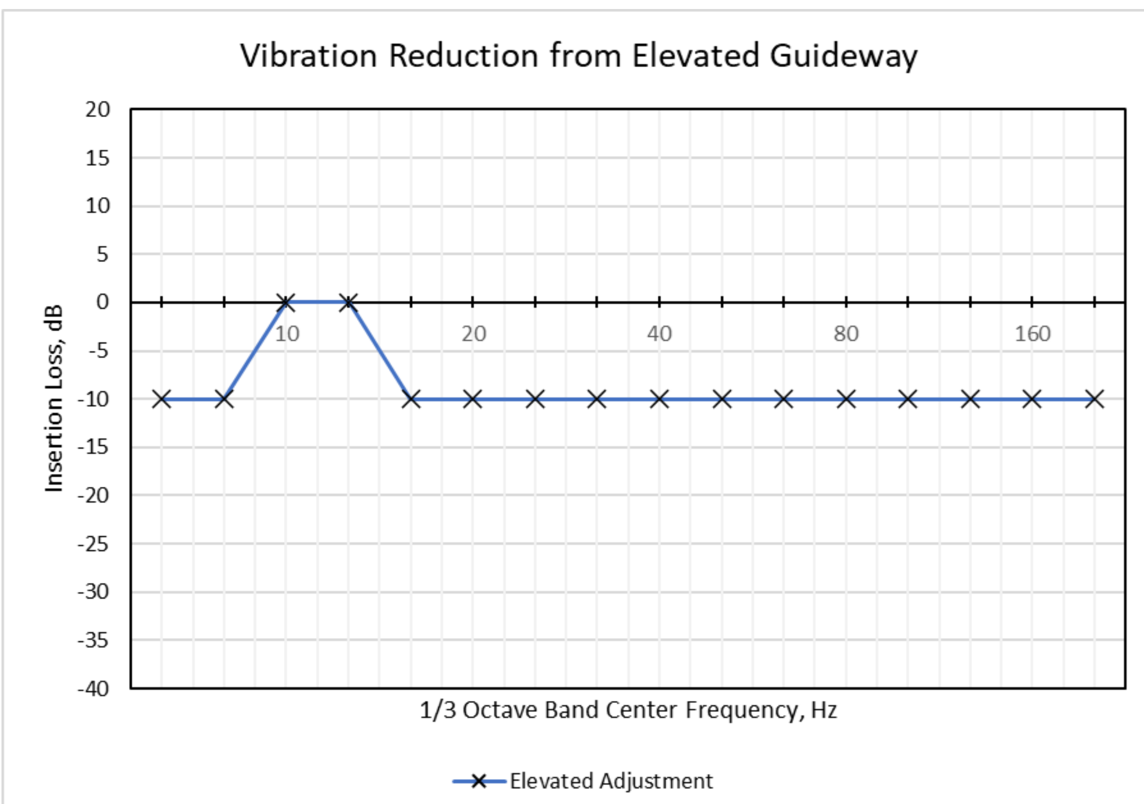


Figure 4-2. Vibration Reduction from Elevated Track Structure



The line source transfer mobility measurement sites and results are discussed in Section 5.3, Vibration Measurements. The data were collected at surface sites in areas where elevated or at-grade track is proposed and at below-grade or borehole sites where tunnels are proposed. The approach used for predicting vibration from light rail operations was to average the line source transfer mobilities measured throughout the project study area. Separate averages were developed for the surface sites and borehole sites. The line source transfer mobility results showed similar trends at sites throughout the project study area, indicating the average is a reasonable approximation to use in the prediction model. For Category 1 sensitive receivers where site-specific line source transfer mobility data were collected, the site-specific data were applied as opposed to the averaged data. Figures 4-3 to 4-6 show the line source transfer mobility curves for the surface and borehole data at 25 feet, 50 feet, 100 feet, and 200 feet, respectively. The borehole data are only shown at 100 feet and 200 feet because the data were usually collected at depths of 80 feet or greater.

The line source transfer mobility data were applied to sensitive receivers throughout the study area as follows:

- Surface West Seattle: Applied to sensitive receivers near elevated, at-grade, or retained-cut track in the West Seattle Junction, Delridge, or Duwamish segments.
- Borehole West Seattle: Applied to sensitive receivers near tunnel track in the West Seattle Junction, Delridge, or Duwamish segments.

Figure 4-3. Average Line Source Transfer Mobility at 25 Feet for Surface Measurement Sites

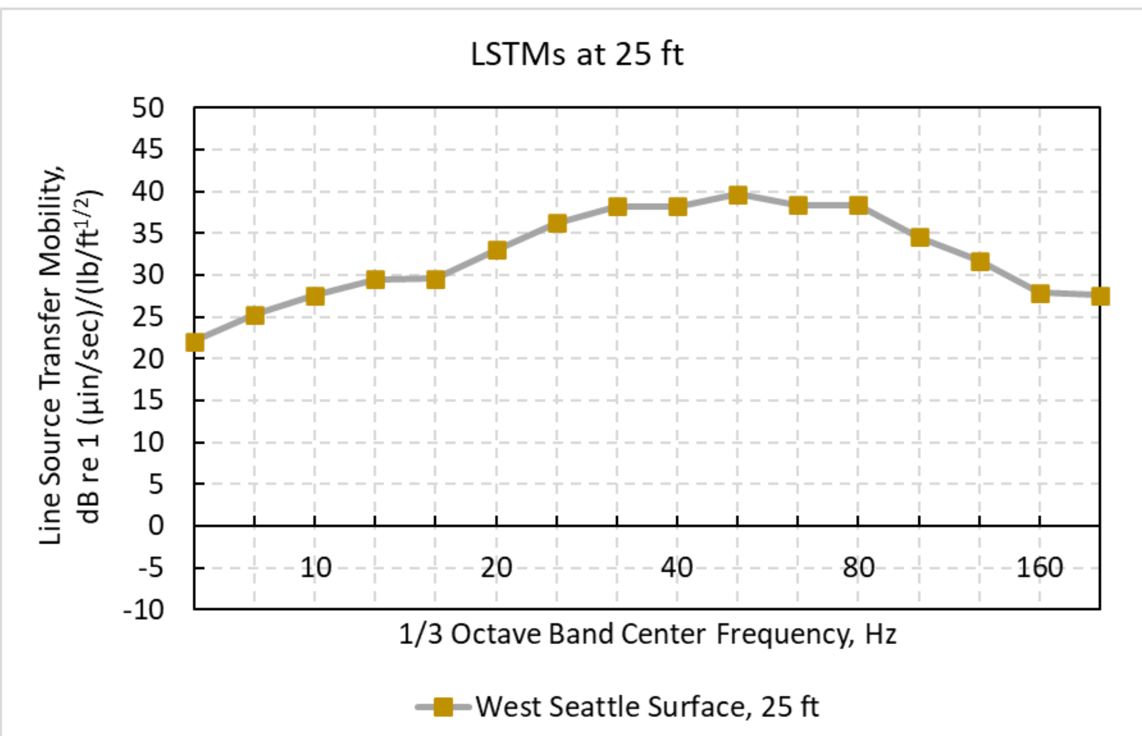


Figure 4-4. Average Line Source Transfer Mobility at 50 Feet for Surface Measurement Sites

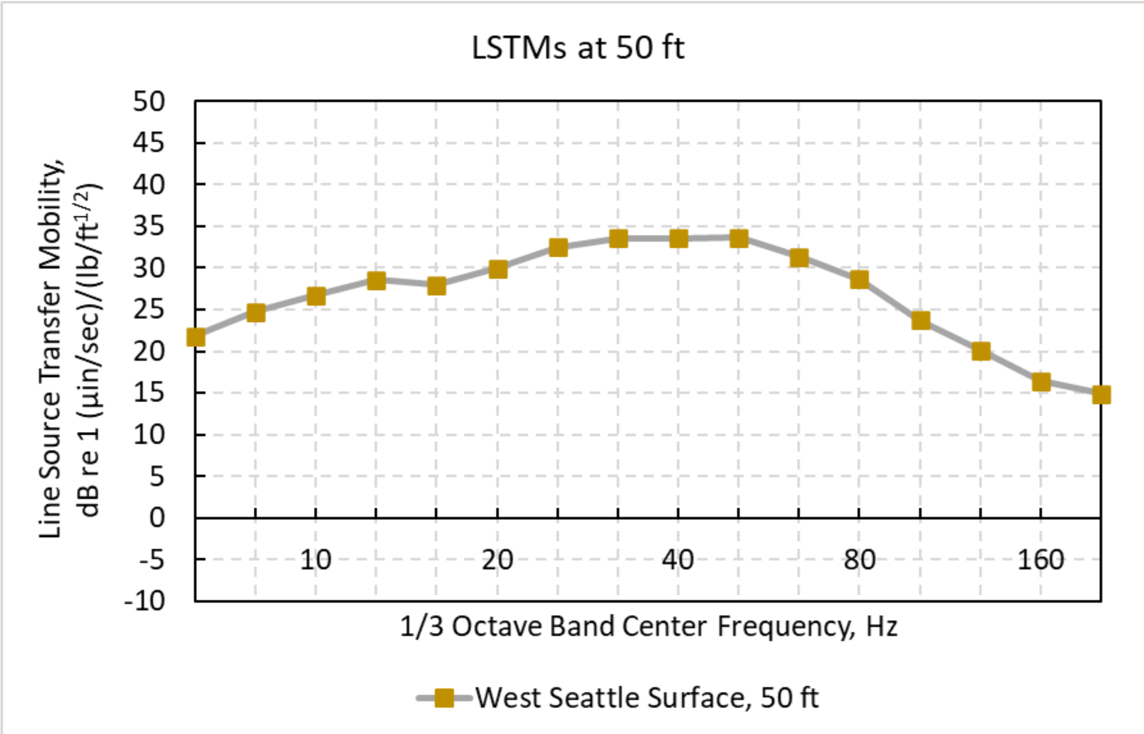


Figure 4-5. Average Line Source Transfer Mobilities at 100 Feet for Surface and Borehole Measurement Sites

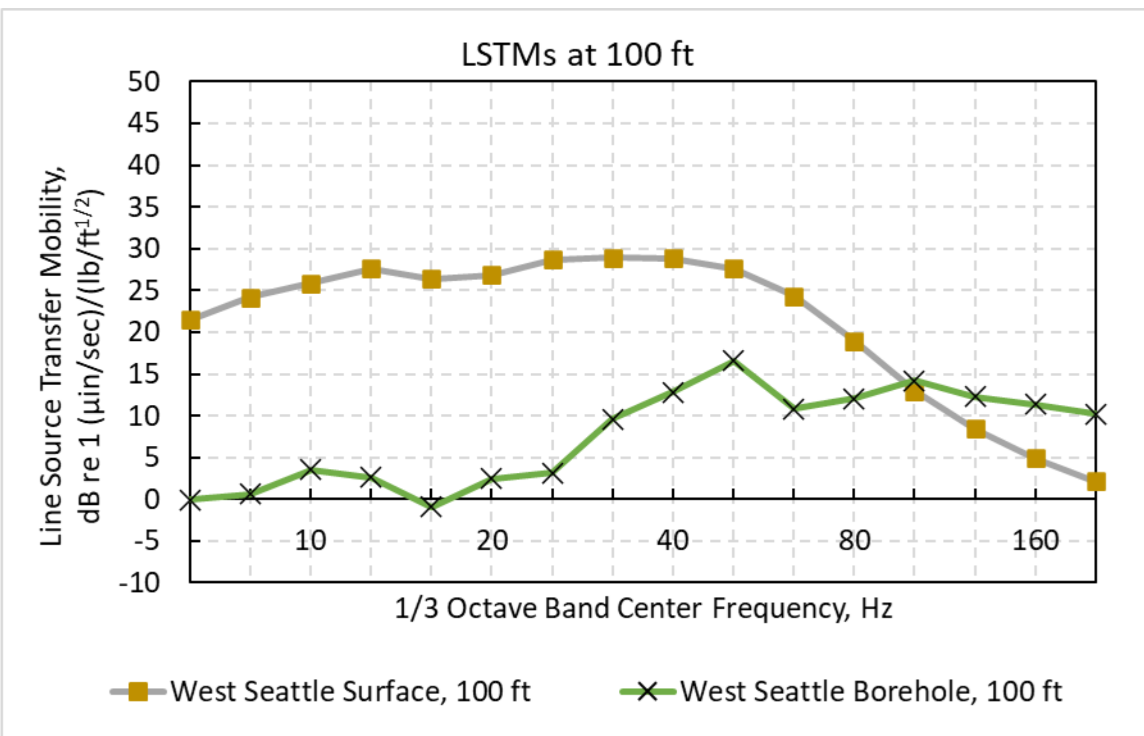
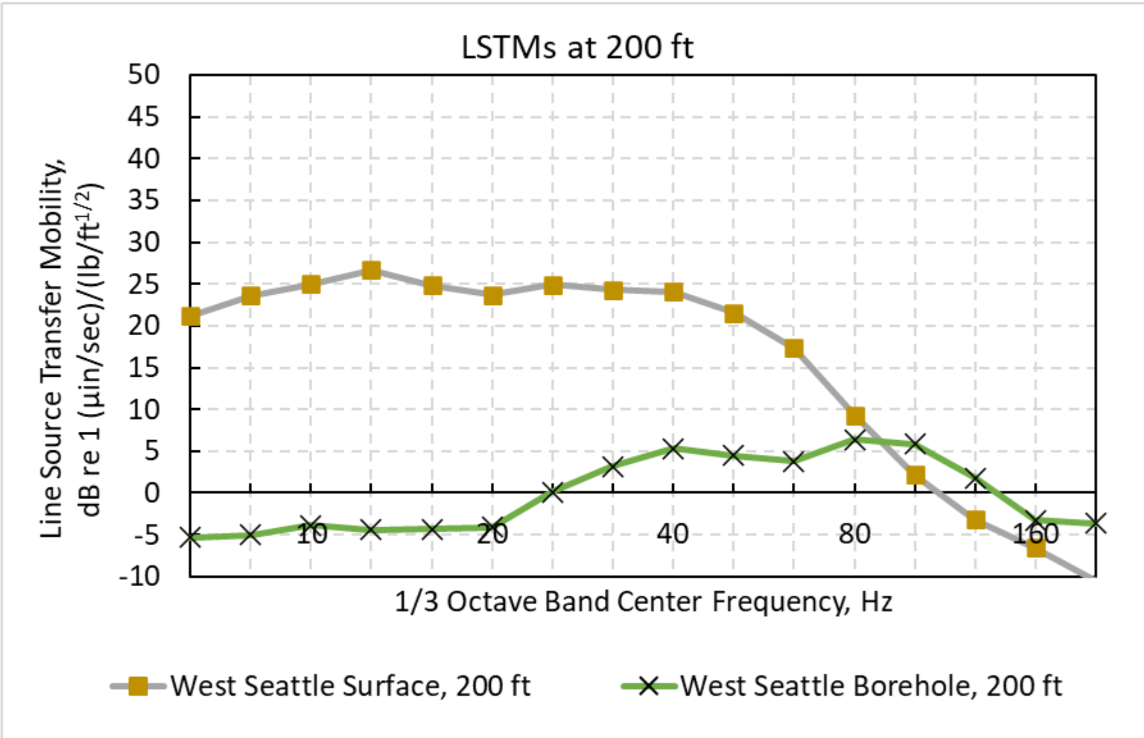


Figure 4-6. Average Line Source Transfer Mobilities at 200 Feet for Surface and Borehole Measurement Sites



The prediction model includes a safety factor of +3 dB to each 1/3-octave band to account for uncertainties in the line source transfer mobility and potential uncaptured amplification effects inside buildings. When vibration is propagated from the ground to the building foundation there is loss in vibration energy at the buildings' interface with the ground, which is commonly referred to as coupling loss. Floor amplification may occur due to resonances of the floors and varies greatly, depending on the type of construction. For the combined effect of coupling loss and floor amplification, the FTA Guidance Manual (2018) recommends a net adjustment of +1 dB for the vibration inside a typical residence. A Transit Cooperative Research Program study based on 35 outdoor-indoor vibration measurements in several cities in North America showed an average outdoor-indoor amplification of 0 dB with a standard deviation of approximately 5 dB (Zapfe et al. 2009, McKenna 2011).

With the exception of Category 1 buildings with building-specific measurement data, it was assumed that the coupling loss and building amplification was a net 0-dB effect. The safety factor of +3 dB is a conservative approach that ensures that in the majority of cases the predicted vibration levels are higher than what would occur when the new project is operational. For Category 1 buildings with site-specific measurements, a measured building adjustment was applied to the predicted level. The measured building adjustments for those Category 1 buildings are presented in Attachment N.3H, Vibration Analysis of Category 1 Uses and Special Buildings.

Another source of vibration accounted for in the prediction model is special trackwork. The wheel impacts at the gaps in the rail at special trackwork for turnouts and switches increases vibration levels. The prediction model for this assessment applies the special trackwork adjustment recommended in the FTA Guidance Manual (2018): Wheel impacts are assumed to cause a localized increase in vibration of 10 VdB up to a distance of 100 feet and an increase in vibration of 5 VdB from 100 to 200 feet.

Track curvature can increase vibration levels. The prediction model assumes an increase in force density level (Ccurv) for tracks with curve radius less than 6,000 feet using the following formula:

$$Ccurv\ (decibel) = 3280\ feet/radius\ (feet)$$

The force density level adjustment for curves with radius less than 1,150 feet is limited to +3 dB.

Groundborne noise refers to the noise generated by groundborne vibration. The relationship between the predicted groundborne vibration, Lv, and the predicted groundborne noise is equal to the vibration velocity plus the A-weighting adjustment at the 1/3-octave band center frequency plus an adjustment to account for the conversion from vibration velocity level to sound pressure level (Krad), such as any acoustical absorption in the room. The FTA Guidance Manual (2018) recommends a Krad value of -5 for typical residential rooms. This analysis assumes a Krad value of -5 decibels for all sensitive receivers.

4.2.2 Construction Vibration Prediction Methods

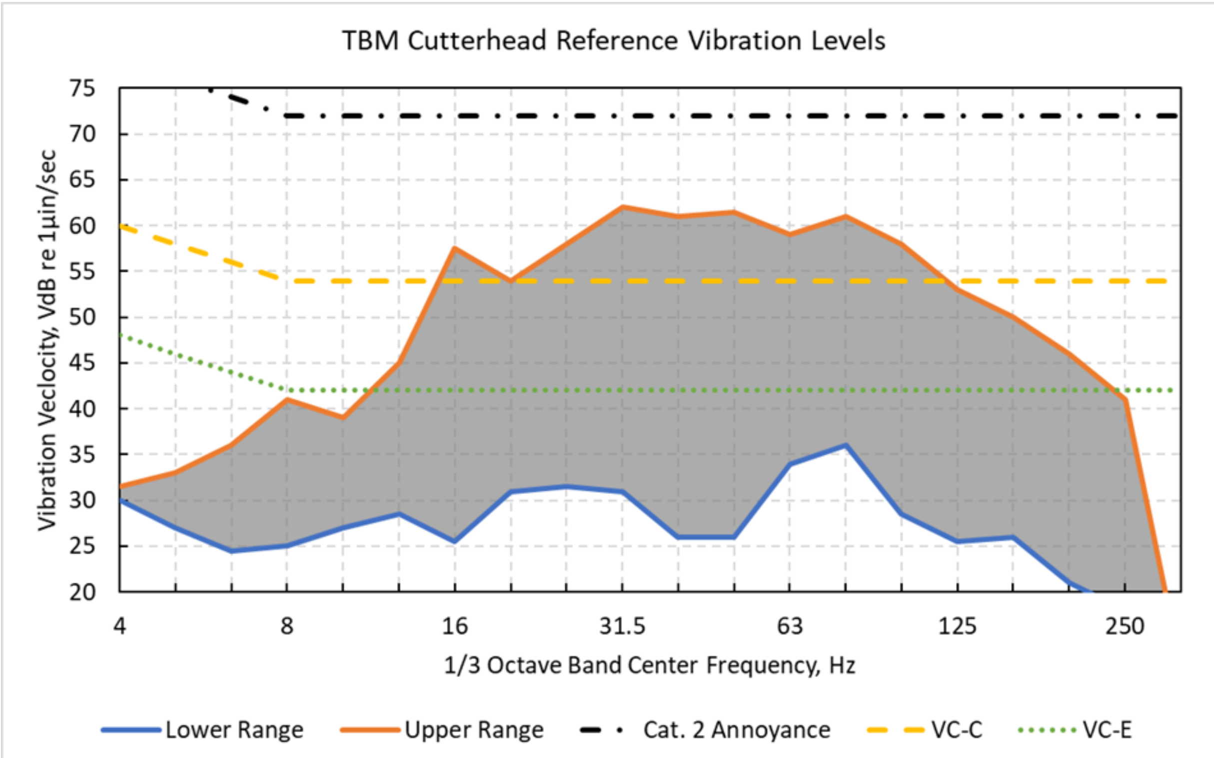
Vibration associated with construction of the West Seattle Link Extension generally falls into two categories: tunneling operations and surface construction activities. Several different alignment alternatives are under consideration and detailed means and methods of construction have not been determined. Therefore, the construction vibration analysis focuses on determining the minimum distance between sensitive receivers and major vibration-generating equipment pieces that would exceed the construction vibration criteria. An analysis specific to Category 1 land uses in the study area has also been conducted to determine the potential for interference with sensitive activities at those facilities.

4.2.2.1 Tunneling Construction Vibration

Many areas of the alignments under consideration include tunnels constructed by an earth pressure balance tunnel boring machine. The machine removes soil and rock via a rotating cutterhead at the front, followed by hydraulic thrust jacks that are temporarily extended to hold the tunnel wall in place. Each time the cutterhead advances 5 feet, the thrust jacks are retracted and replaced with concrete tunnel liner segments. The liner segments are delivered from the tunnel supply shaft to the tunnel boring machine via a temporary rail system, positioned on the tunnel wall by a vacuum erector and bolted into place with handheld pneumatic impact wrenches. The main sources of vibration during this process are tunnel boring machine cutterhead mining, thrust jack retraction during liner segment installation, and operation of the supply train for workers and materials. A vibration prediction model for these tunneling activities was developed using measured data from tunneling under the University of Washington main campus (Bergen and Schwarz 2015, Bergen et al. 2012).

Operation of the tunnel boring machine cutterhead can generate a large range of vibration levels that is affected by underground features such as cobbles as well as the type of surrounding soil being tunneled through. Measurements conducted during tunneling under the University of Washington main campus suggest that vibration levels from the tunnel boring machine cutterhead are generally higher in areas of sandy soils and lower in clay/silt soils. Reference levels for the tunnel boring machine cutterhead vibration analysis have been based on those measurements at the University of Washington and are shown on Figure 4-7. A range of values are included to account for the variability in the cutterhead vibration levels due to depth, soil type, and underground features like cobbles. The reference levels were measured at distances ranging from 0 feet to over 200 feet horizontally along the surface from the tunnel centerline, and the range of reference levels are considered valid for those distances.

Figure 4-7. Reference Vibration Levels for Tunnel Boring Machine Cutterhead Operation

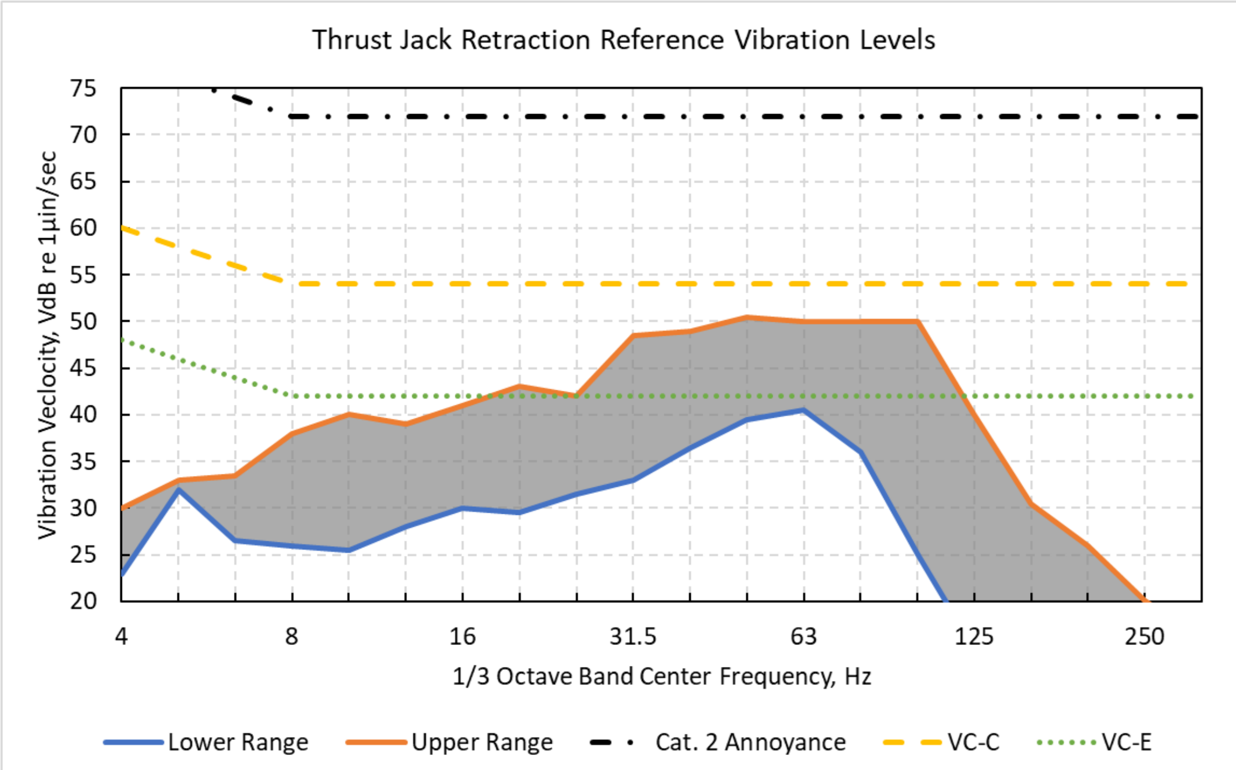


Source: Bergen et al. 2012.

Vibration levels generated as the concrete liner segments are positioned and bolted into place are negligible, and usually below the existing ambient vibration levels at the surface. However, retraction of the hydraulic thrust jacks during the liner segment installation has the potential to generate high levels of vibration if it includes a hard stop, when the cylinders are retracted at full speed. Reference vibration levels of thrust jack retraction measured during the University of Washington tunnel construction are shown on Figure 4-8. The reference level range accounts for the variability in vibration levels due to the tunnel depth and nearby soil type and are considered valid for distances from 0 to 200 feet measured horizontally from the tunnel centerline.

The supply train may be used to transport workers and materials from the portal or tunnel supply shaft to the tunnel boring machine. A supply train typically travels at 12 miles per hour and consists of steel-wheeled flatbed trailers pulled by a diesel locomotive. The rail is progressively laid out in short sections as the boring machine travels along its path, and the rail often includes some level of damage on the running surface. Gaps of up to 3/4 inch between adjoining rail sections were noted during tunneling for the University Link project. Both the uneven rail running surface and the rail gaps contribute to higher vibration levels. Rail sections are installed either by using pre-assembled rail fastened to wooden ties, or by fastening the rail to temporary steel ties bolted directly to the tunnel invert.

Figure 4-8. Reference Vibration Levels for Thrust Jack Retraction

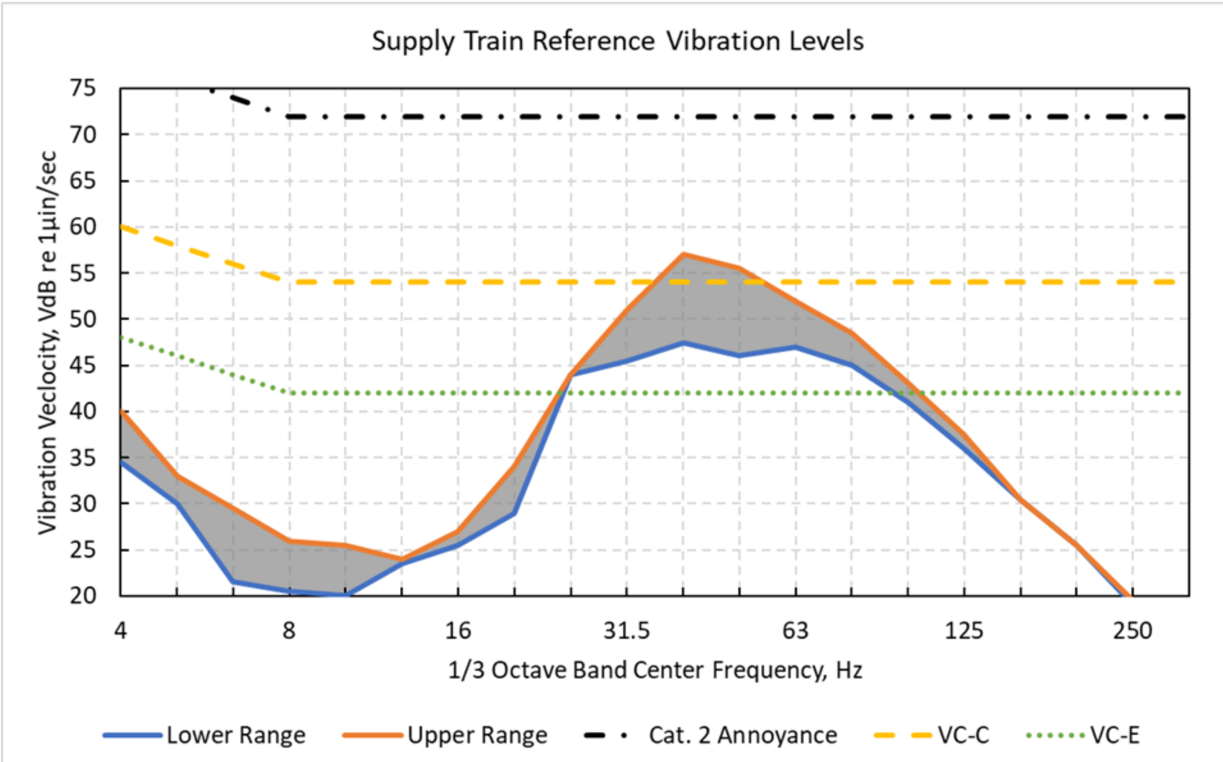


Source: Bergen et al. 2012.

Reference vibration levels for a supply train running at 12 miles per hour on uneven rail are shown on Figure 4-9 and are given as a range of values based on measurements conducted during the University of Washington tunnel construction. The range of values accounts for the variability in vibration levels due to the tunnel depth and nearby soil type and are considered valid for distances from 0 to 200 feet measured horizontally from the tunnel centerline.

As discussed in Section 2.2, Vibration Fundamentals and Descriptors, groundborne noise is a low-frequency rumble caused by room surfaces radiating sound waves as they vibrate. A groundborne noise assessment is not included in most construction assessments because the airborne noise generated by the construction is typically higher than the groundborne noise. However, because there is no airborne noise path during tunneling a groundborne noise assessment has been conducted for these activities. The impact assessment is presented in Section 6.4, Construction Vibration Impacts.

Figure 4-9. Reference Vibration Levels for Tunnel Boring Machine Supply Train (12 miles per hour with uneven rail)



Source: Bergen et al. 2012.

4.2.2.2 Surface Construction Vibration

Surface construction activities often include the use of high-vibration equipment pieces, the most common of which are listed in Section 6.4.2, Surface Construction Vibration Impacts. The reference vibration levels for the analysis come from the FTA Guidance Manual (2018) and are shown as peak particle velocity levels, which quantify the maximum vibration velocity from a piece of equipment at a distance of 25 feet. The damage criteria for buildings as discussed in Section 3.2.2, Groundborne Noise Criteria, is in terms of peak particle velocity. However, the criteria for sensitive equipment and occupant annoyance (Section 3.2.1, Transit Vibration Criteria) is in VdB, which are a root mean square of a vibration velocity signal. The ratio of the peak particle velocity to the max root mean square level is called the crest factor and is typically between 4 and 5. A crest factor of 4 has been used for this analysis. The equation below is used to convert from peak particle velocity (inches per second) to a vibration level L_v (VdB):

$$L_v = 20 \times \ log_{10}\left(\frac{peak\ particle\ velocity}{crest\ factor\ \times\ 10^{-6}}\right)$$

In most cases, construction equipment will not be operating at the 25-foot reference distance, so a distance correction is needed. The following equation is used to convert peak particle velocity reference values to a desired distance:

$$peak\ particle\ velocity_{equip} = peak\ particle\ velocity_{ref} \times \left({D_{ref}}/{D_{equip}}\right)^{1.5}$$

where D_{ref} is the reference distance (typically 25 feet) and D_{equip} is the distance between the equipment and the sensitive receiver. Typically, the minimum distance each piece of equipment is expected to operate from a sensitive receiver is determined and vibration predictions are made based on that distance using the equation above. The predictions are compared to the criteria to determine whether impacts are expected. This type of analysis is not possible at this stage because detailed information about construction means and methods and site layouts are not available. Instead, the equation above was used to determine the distance from a sensitive receiver at which each piece of equipment would generate vibration levels equal to the impact threshold. The result of this analysis is presented in Section 6.4.2.

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5 AFFECTED ENVIRONMENT

Sound Transit identified noise- and vibration-sensitive locations throughout the project corridor and selected locations where noise monitoring and vibration testing would be performed. The study area for noise is based on measured noise levels of the existing fleet of Sound Transit light rail vehicles, operational schedule, and train speeds, and is large enough to capture all potential noise impacts from system operations. Based on this information, the analysis includes noise-sensitive properties within at least 500 feet of the track alignments.

The potential area of effect for the vibration study is smaller compared to noise because vibration levels attenuate more rapidly. The potential area of effect for the vibration study is 200 feet from the track alignment for most land uses, such as residences and schools, and 450 feet from the track alignment for more vibration-sensitive land uses such as research laboratories or recording studios.

The following sections describe the land uses along the West Seattle Link Extension corridor, the existing noise-level measurements, and the current noise sources in the corridor. A more detailed discussion of land use can be found in Section 4.2, Land Use, of the Final EIS. The land uses are summarized for their potential sensitivity to noise and vibration. Most identified sensitive land uses are sensitive to both noise and vibration. The exceptions include outdoor parks, which may be noise-sensitive depending on usage but are not vibration-sensitive, and vibration-sensitive equipment (such as a magnetic resonance imaging machine), which are not sensitive to airborne noise. The tunnel segments would not generate airborne noise during operations. As such, sensitive receivers near tunnel segments are only assessed for groundborne noise and vibration impacts and not airborne noise during operations.

5.1 Noise- and Vibration-sensitive Receivers

This section provides an overview of the noise- and vibration-sensitive receivers along the corridors being evaluated for the West Seattle Link Extension. Chapter 3, Noise and Vibration Impact Criteria, of this document defines the land use types considered as noise- and vibration-sensitive under the FTA assessment methodology (FTA 2018). For a more detailed presentation of land uses, refer to Section 4.2 of the Final EIS.

5.1.1 SODO Segment

No noise- or vibration-sensitive properties were identified in the SODO Segment. Land uses in this segment are predominantly industrial and commercial (Figure 5-1). Alternatives in this segment would be a mix of at-grade and elevated options.

The SODO Trail, a 1-mile urban bicycle and pedestrian trail, runs along the east side of the light rail line between South Royal Brougham Way and South Forest Street. Based on the land uses, there was no noise or vibration analysis required.

6/24/2024 | WSLE Seg SODO | Exist_Landuse_SEG.aprx

Source: City of Seattle, King County (2023).

Preferred Alternative

- Elevated
- Retained Cut
- At-Grade

Other Alternatives

- Elevated
- Retained Cut
- At-Grade

Station (● *Indicates Preferred Alternative*)

- New
- Existing
- Relocated

- Segment Line
- Existing Link Light Rail
- Railroad
- SODO Busway
- Proposed Overpass

Existing Land Use

- Commercial
- Institutional/Public
- Industrial

FIGURE 5-1
Existing Land Use
SODO Segment

West Seattle Link Extension

0 500 1,000 Feet

N

5.1.2 Duwamish Segment

Similar to the SODO Segment, the Duwamish Segment is predominantly industrial and commercial land uses that are generally not noise- or vibration-sensitive (Figure 5-2).

Noise-sensitive land uses include fire stations, single- and multi-family housing, schools, and a recording studio. The Secret Studio Records/Studio 1208 recording studio, located at 3856 23rd Avenue Southwest, is an FTA Category 1 noise-sensitive land use. The Seattle Fire Department has two fire stations in this segment that are considered noise-sensitive because they have sleeping quarters (FTA Category 2): Fire Station 14 at 3224 4th Avenue South, and Fire Station 36 at 3600 23rd Avenue Southwest. On the west side of the segment, there are single- and multi-family residences in the Pigeon Point and Riverside communities. Single- and multi-family housing, public and institutional uses (Pathfinder K-8 School), the Delridge Connector Trail (paved bicycling and walking trail), and open space (West Duwamish Greenbelt) are all in the Pigeon Point community. The only part of West Duwamish Greenbelt that is near the Link light rail alignments are along the steep hillside near Pigeon Point, which is south of the West Seattle Bridge, dominated by noise from traffic on the bridge, and not an area with public access; therefore, it is not considered noise-sensitive under FTA criteria.

Vibration-sensitive land uses also include fire stations, single- and multi-family housing, schools, a recording studio, and a precision machining facility. The Category 2 (residential) and Category 3 (institutional) vibration-sensitive land uses in the Duwamish Segment are the same as the described noise-sensitive land uses. The Harbor Island Machine Works at 3431 11th Avenue Southwest is a precision machining company and is the only Category 1 vibration-sensitive land use in the Duwamish Segment, while the Secret Studio Records/Studio 1208 recording studio at 3856 23rd Avenue Southwest is the only special-use building.

The Bootstrap Music Company, located in the industrial area near the east end of the West Seattle Bridge, provides music rehearsal space for rent but is not considered noise- or vibration-sensitive under FTA criteria because its use is compatible with higher noise and vibration levels. This area would have higher existing noise levels as there is freight train activity and frequent heavy truck traffic in close proximity to the building.

5.1.3 Delridge Segment

Noise-sensitive uses in the Delridge Segment include residential uses, schools and childcare centers, parks, and open spaces as described below.

Most of this segment is single or multi-family residential land uses (Figure 5-3). Several multi-family residential uses are concentrated along Southwest Avalon Way, north of Southwest Genesee Street. There is some non-noise-sensitive commercial development along Delridge Way Southwest. In addition to many residential uses, other noise-sensitive uses include Alki Beach Academy at 2414 Southwest Andover Street, Mode Music Studios at 3805 Delridge Way Southwest, and the Youngstown Cultural Arts Center at 4408 Delridge Way Southwest (FTA Category 3).

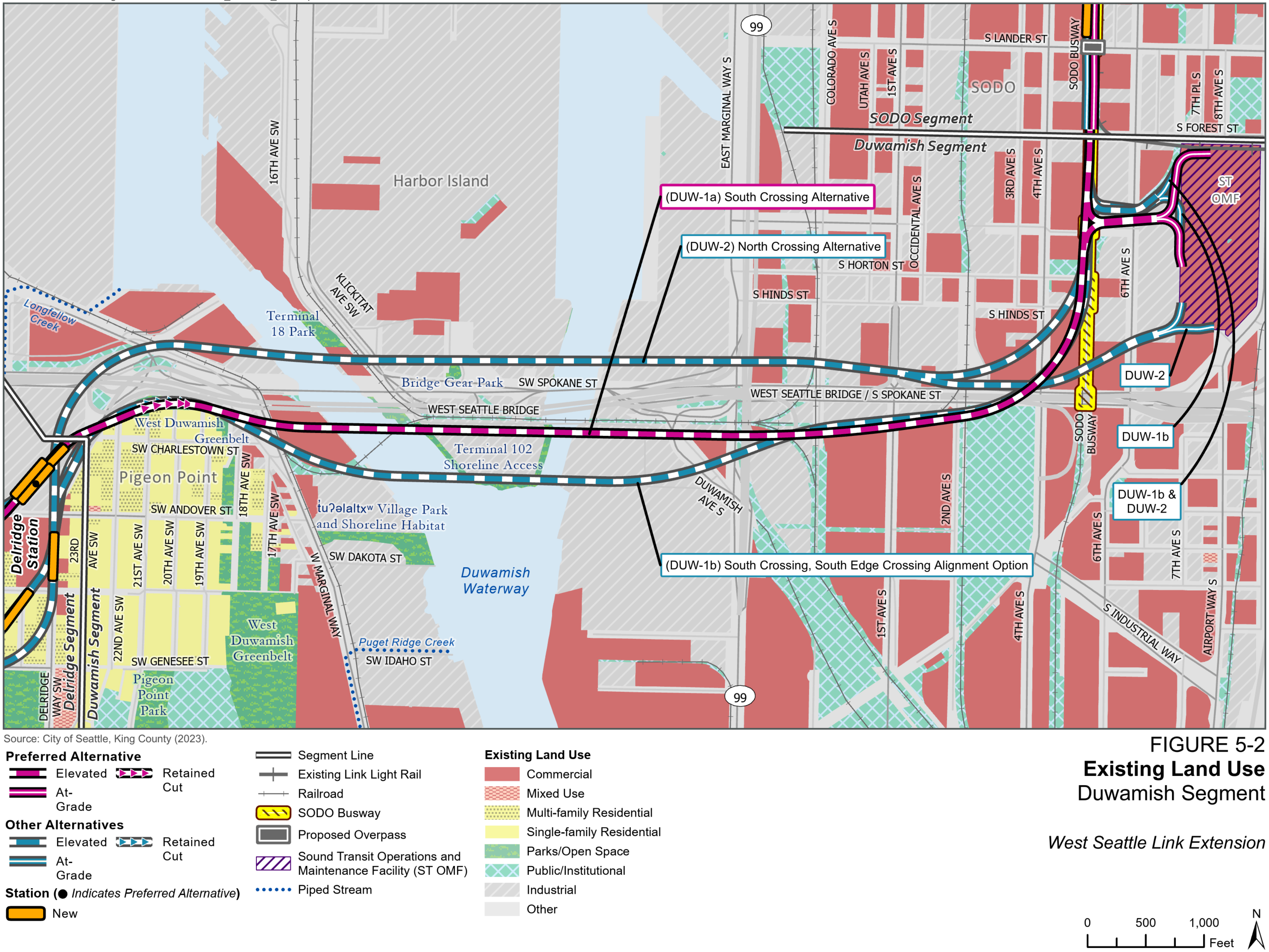
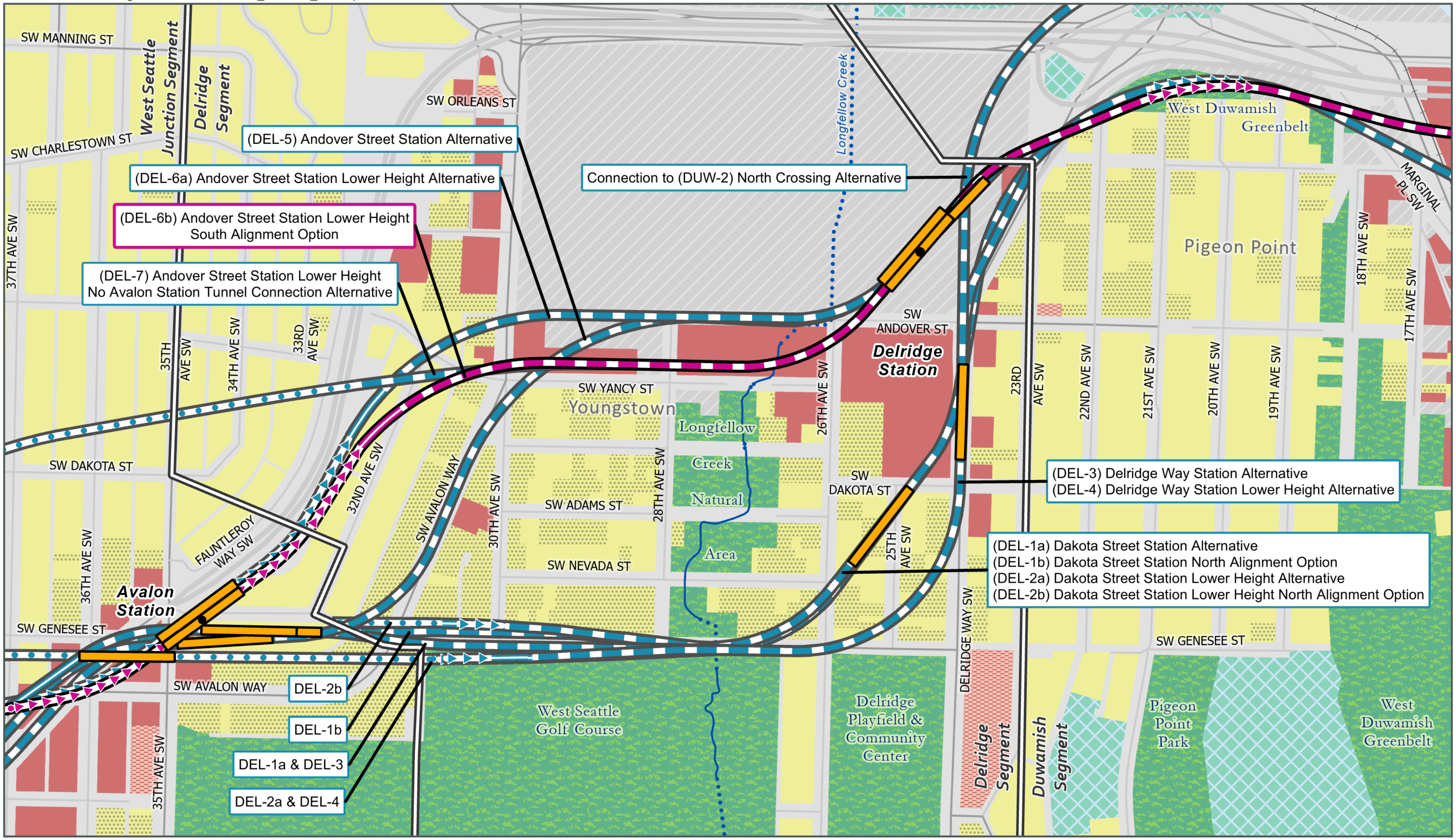


FIGURE 5-2
Existing Land Use
Duwamish Segment

West Seattle Link Extension



Source: City of Seattle, King County (2023).

Preferred Alternative

- Elevated
- Tunnel
- At-Grade
- Retained Cut

Other Alternatives

- Elevated
- Tunnel
- At-Grade
- Retained Cut

Station (● *Indicates Preferred Alternative*)

- New

- Segment Line
- Railroad
- Stream
- Piped Stream

Existing Land Use

- Commercial
- Mixed Use
- Multi-family Residential
- Single-family Residential
- Parks/Open Space
- Public/Institutional
- Industrial
- Other

0 500 1,000 Feet N

FIGURE 5-3
Existing Land Use
Delridge Segment

West Seattle Link Extension

Parks and active outdoor uses include the West Seattle Golf Course, Longfellow Creek Natural Area, and Delridge Playfield and Community Center; however, due to the locations and existing noise levels, only parts of the Longfellow Creek Natural Area were considered noise-sensitive under the FTA criteria. Noise-sensitive parts of the Longfellow Creek Natural Area include the portions of the park that have lower noise levels and are not near arterial roadways in the area, including Southwest Genesee Street. Locations selected for analysis at the Longfellow Creek Natural Area include the trail just north of Southwest Nevada Street and the area near the Dragonfly Garden and Pavilion.

A small portion of this segment is within the Duwamish Manufacturing/Industrial Center and includes Nucor Steel, a steel manufacturing plant, also not considered noise- or vibration-sensitive under FTA criteria.

In the Delridge Segment, the vibration-sensitive receivers are the same as the noise-sensitive receivers.

5.1.4 West Seattle Junction Segment

Noise- and vibration-sensitive properties in the West Seattle Junction Segment include a mix of single- and multi-family residences, childcare centers, a fire station, and places of worship as described in the following paragraphs (Figure 5-4).

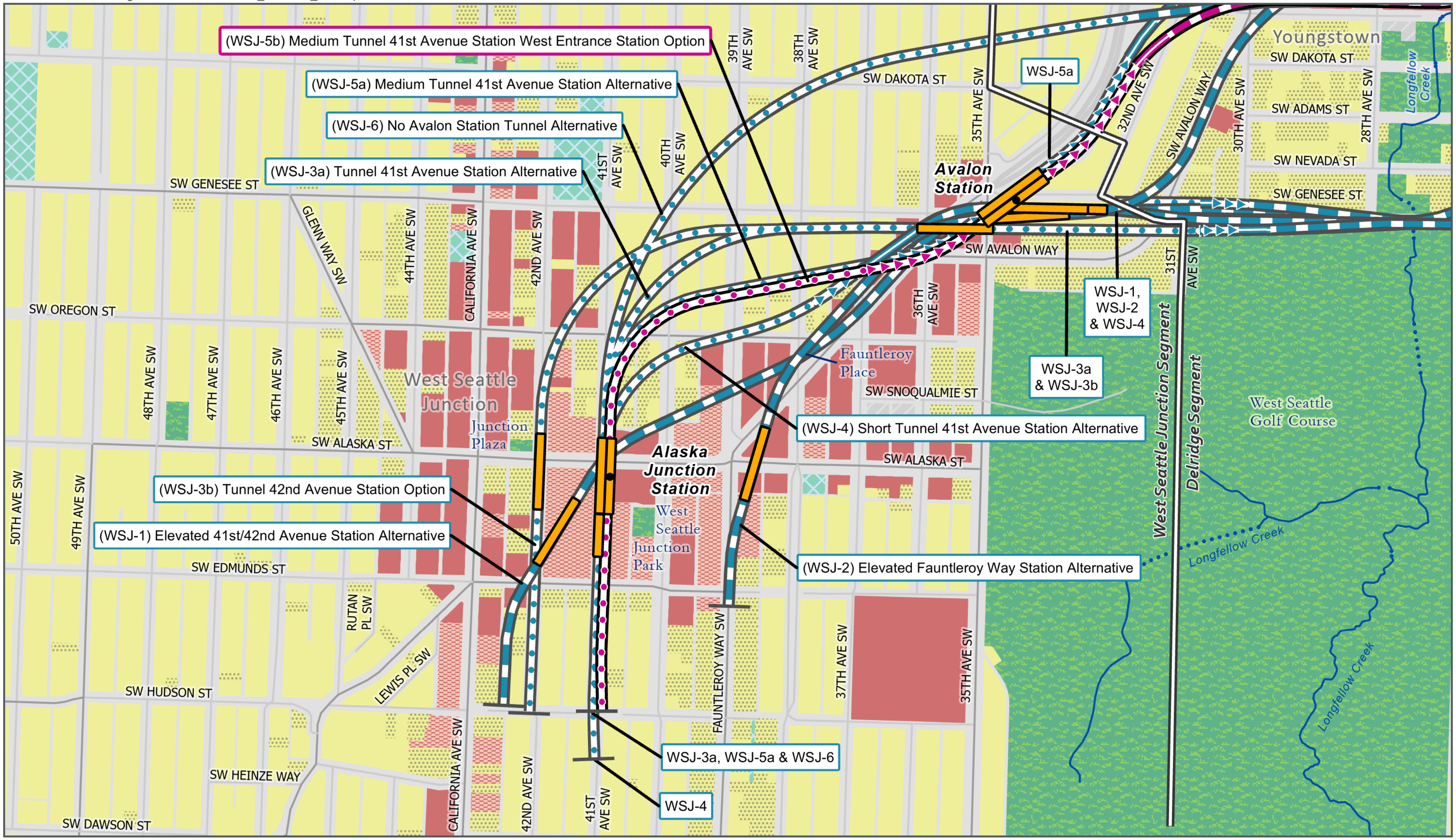
This segment includes the West Seattle Junction hub urban village, where there is an active mixed-use district serving the surrounding single- and multi-family residential areas. Fire Station 32 is in this segment at 3715 Southwest Alaska Street and is considered noise-sensitive because it has sleeping quarters (FTA Category 2). Commercial and mixed-use development is mostly clustered along Fauntleroy Way Southwest, Southwest Alaska Street, and California Avenue Southwest and includes childcare centers such as Bright Horizons at 4530 38th Avenue Southwest and the West Seattle Family Y.M.C.A. at 3622 Southwest Snoqualmie Street. The West Seattle Stadium is also in this segment; however, active sports complexes, including the West Seattle Stadium, are not considered noise- or vibration-sensitive under FTA criteria. Two places of worship are also in this segment, the Eastridge Church at 4500 39th Avenue Southwest and the Calvary Chapel West Seattle at 4217 Southwest Oregon Street.

Sensitive receivers within the screening distance of the tunnel alternatives are assessed for groundborne noise and vibration impacts, but not for airborne noise.

5.2 Noise Measurements

Sound Transit characterized the existing noise environment through onsite inspections and onsite noise monitoring. Monitoring was performed at 42 locations, including 22 long-term (approximately 48-hour or more) and 20 short-term (30-minute) sites. Long-term monitoring was performed at locations representative of nearby residential use properties. Short-term monitoring was conducted near residences and nonresidential use properties, such as parks and schools. Sound Transit also collected traffic counts at several of the short-term noise monitoring locations to predict noise impacts from changes to roadways associated with project construction.

Noise monitoring locations were selected based on land use, existing noise sources, proximity to light rail alternatives and profile types, representative land uses, and access allowed by the property owner (when not in the public right-of-way). Long-term noise monitoring was primarily used to establish the existing 24-hour Ldn along the corridor. Where long-term monitoring was not practical, short-term monitoring was conducted to supplement nearby long-term monitoring sites, and to support the traffic noise analysis.



Source: City of Seattle, King County (2023).

Preferred Alternative
- Elevated
- Tunnel
- At-Grade
- Retained Cut

Other Alternatives
- Elevated
- Tunnel
- At-Grade
- Retained Cut

Station (● *Indicates Preferred Alternative*)
- New

- Segment Line
- Stream
- Piped Stream

Existing Land Use
- Commercial
- Mixed Use
- Multi-family Residential
- Single-family Residential
- Parks/Open Space
- Public/Institutional
- Industrial
- Other

0 500 1,000 Feet N

FIGURE 5-4
Existing Land Use
West Seattle Junction Segment

West Seattle Link Extension

5.2.1 Measurement Methodology

Noise measurements were conducted in general accordance with the FTA Guidance Manual and the American National Standards Institute procedures for community noise measurements. Measurement locations were at least 5 feet from structures and 5 feet above the ground (where possible) to reduce the effects of acoustical reflections on the measurement results. Traffic counts accompanying the noise measurements were also taken in accordance with the Federal Highway Administration and WSDOT standards.

Equipment used for the noise monitoring included Brüel & Kjaer Type 2250, Svantek SV979, Svantek 958, Svantek SV971, and Svantek SV307 sound level meters. All sound monitoring equipment was calibrated before and after the measurements using acoustic calibrators. Measurement equipment was calibrated within 1 year of the measurement dates by an accredited testing laboratory traceable to the National Institute of Standards and Technology. All measurement equipment met or exceeded the requirements for an American National Standards Institute Type 1 noise measurement system.

Measurement periods that included rain or wet road conditions were excluded from the analysis. All Ldn values were calculated from a minimum of 48 hours of data.

Short-term measurements for most locations were made approximately twice per site, at least once in the morning between 7 a.m. and 10 a.m. and again in the afternoon between 3 p.m. and 7 p.m. The reported values from these measurements are the loudest overall Leq measured either in the morning or afternoon.

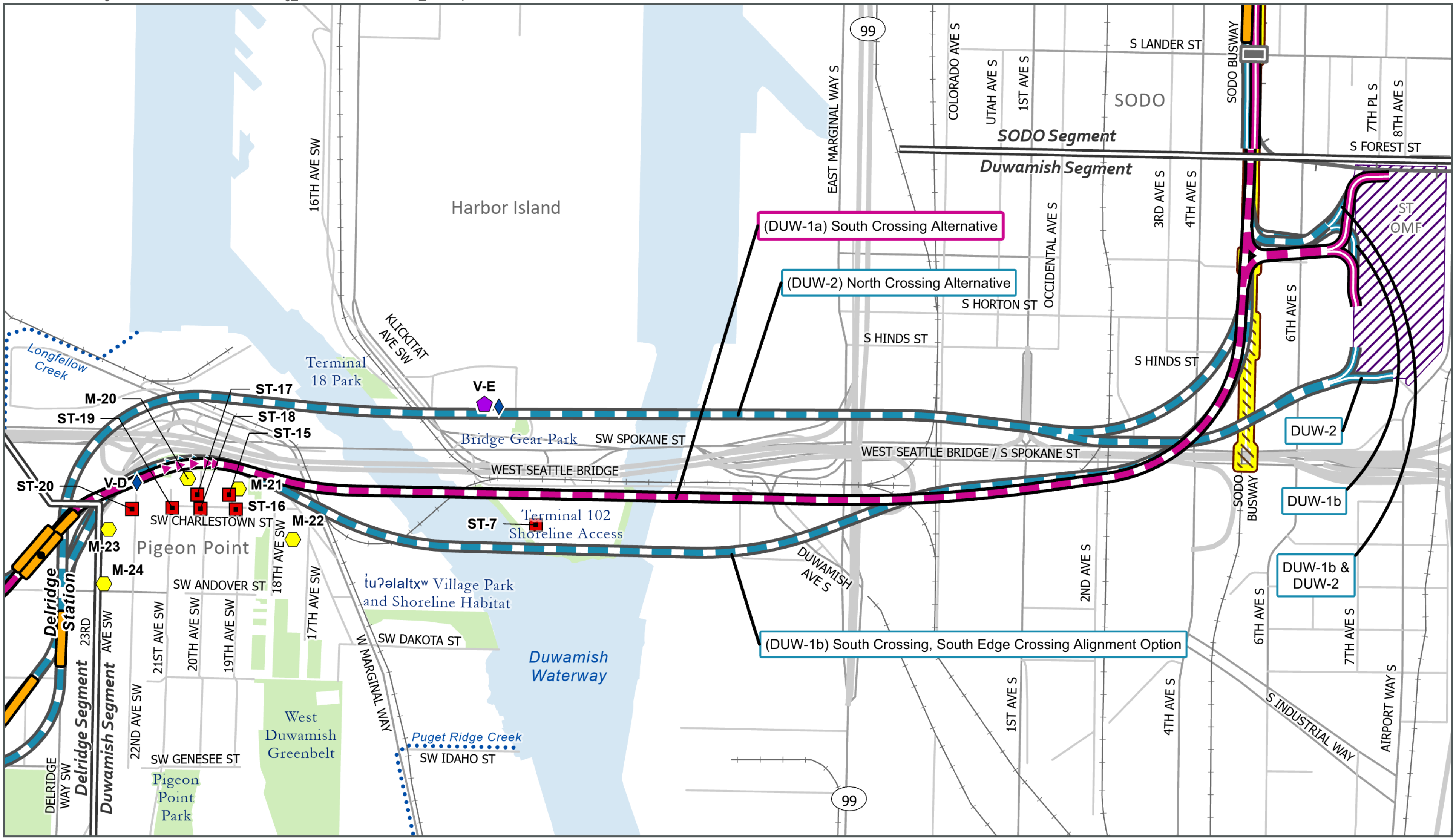
The following sections describe the existing noise environment in the West Seattle Link Extension. It should be noted that noise measurements were not taken in the SODO Segment because adjacent receivers did not warrant noise measurements. In addition, all noise measurements were taken during normal operations of the West Seattle Bridge, and none were taken during the COVID-19 travel restrictions.

Complete results of the monitoring, along with photos of the system installations and locations, are provided in Attachment N.3A, Noise Measurement Data, Site Details, and Photographs.

5.2.2 Existing Noise Measurement Results

The West Seattle Link Extension had 22 long-term and 20 short-term monitoring locations as shown on Figures 5-5 through 5-7. Sound levels in the project area are dominated by traffic noise on major arterial roadways, such as the West Seattle Bridge, Fauntleroy Way Southwest, West Marginal Way Southwest, and Delridge Way Southwest. Table 5-1 summarizes ambient noise monitoring for the West Seattle Link Extension, which includes the monitoring locations, addresses, land use, and type of measurements. Although the noise monitoring location numbers may not be shown in order, the monitoring sites are generally presented from east to west.

For the SODO Segment, there are no properties identified that are noise-sensitive under FTA criteria; therefore, no sound levels were measured in this segment.



Source: City of Seattle, King County (2023).

Preferred Alternative
- Elevated
- Retained Cut
- At-Grade

Other Alternatives
- Elevated
- Retained Cut
- At-Grade

Station (● *Indicates Preferred Alternative*)
- New

- Segment Line
- Existing Link Light Rail
- Railroad
- SODO Busway
- Proposed Overpass
- Sound Transit Operations and Maintenance Facility (ST OMF)
- Piped Stream
- Park

Noise Monitoring Locations
- Short Term Monitoring
- Long Term Monitoring

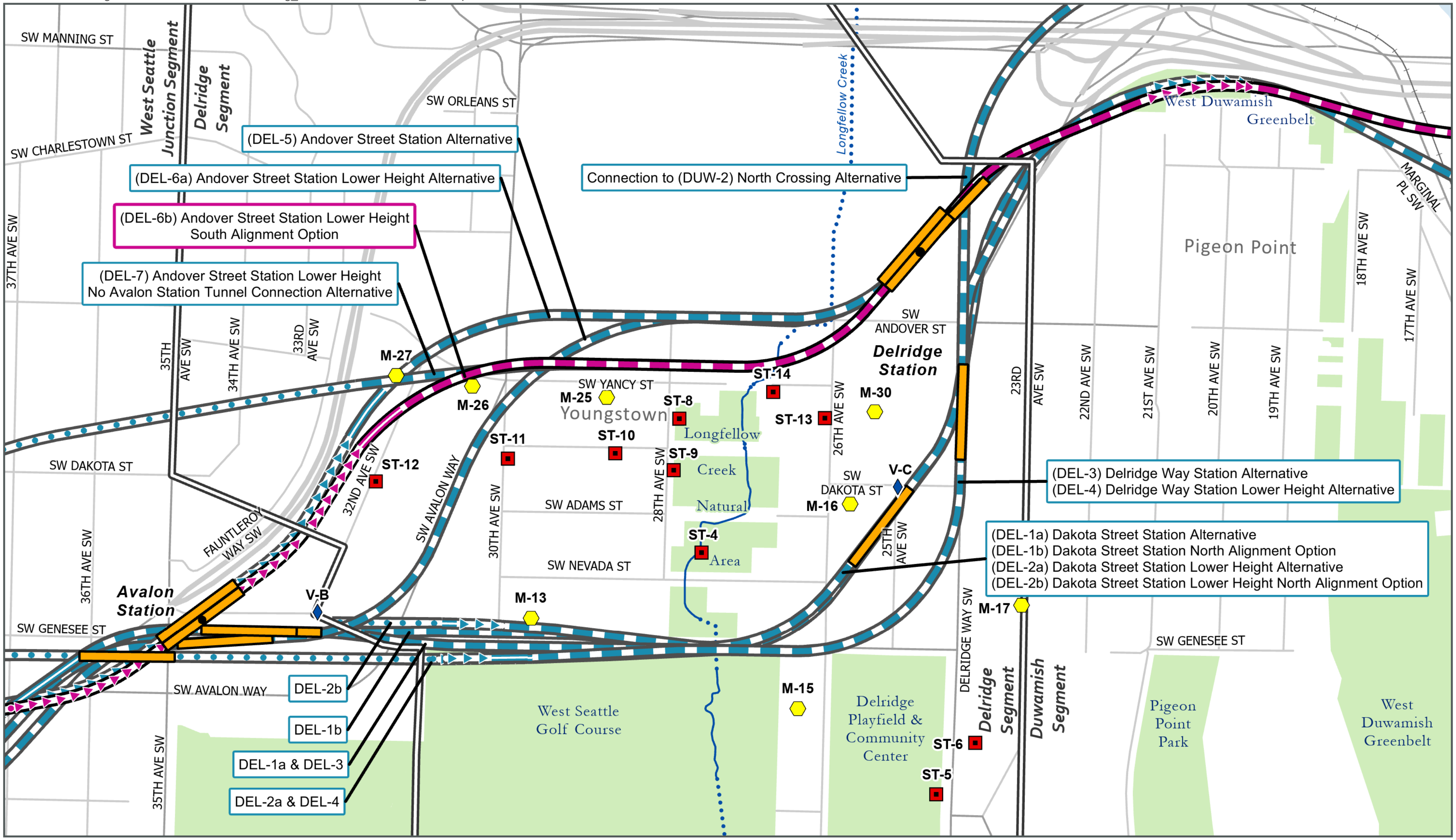
Vibration Measurement Sites
- Existing Vibration Measurement
- At-grade Vibration Propagation

0 500 1,000 Feet
N

FIGURE 5-5
Noise Monitoring Locations and Vibration Measurement Sites
Duwamish Segment

West Seattle Link Extension

6/24/2024 I TR Fig 5-x SEGMENT I NoiseMonitoring_VibrationMeasurement_SEG.aprx



Source: City of Seattle, King County (2023).

Preferred Alternative
- Elevated
- Tunnel
- At-Grade
- Retained Cut

Other Alternatives
- Elevated
- Tunnel
- At-Grade
- Retained Cut

Station (● *Indicates Preferred Alternative*)
- New

- Segment Line
- Railroad
- Stream
- Piped Stream
- Park

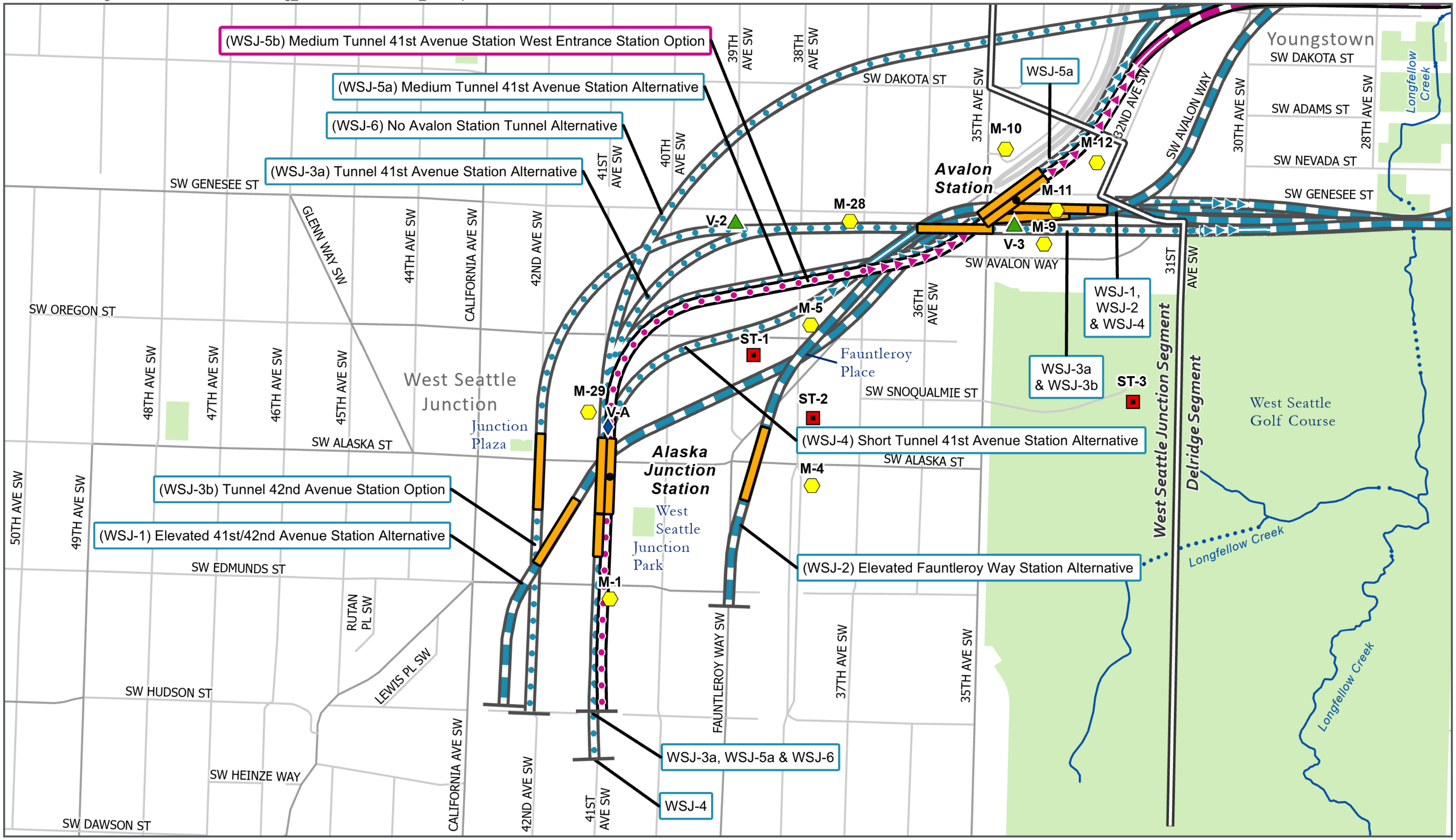
Noise Monitoring Locations
- Short Term Monitoring
- Long Term Monitoring

Vibration Measurement Sites
- At-grade Vibration Propagation

0 500 1,000 Feet
N

FIGURE 5-6
Noise Monitoring Locations and Vibration Measurement Sites
Delridge Segment

West Seattle Link Extension



Source: City of Seattle, King County (2023).

Preferred Alternative

Elevated | Tunnel | At-Grade | Retained Cut

Other Alternatives

Elevated | Tunnel | At-Grade | Retained Cut

Station (● *Indicates Preferred Alternative*)

New

Segment Line
Stream
Piped Stream
Park

Noise Monitoring Locations

Short Term Monitoring
Long Term Monitoring

Vibration Measurement Sites

At-grade Vibration Propagation
Below-grade Vibration Propagation

FIGURE 5-7

Noise Monitoring Locations and Vibration Measurement Sites

West Seattle Junction Segment

West Seattle Link Extension

0 500 1,000 Feet

N

Table 5-1. Noise Measurements

Segment	Monitoring Location	Address	Land Use Type	Type of Measurement	Leq (Daytime-hour Leq in dBA)	Ldn (24-hour Ldn in dBA)
Duwamish	ST-7	1011 Southwest Klickitat Avenue	Commercial	Short-Term	63	59
Duwamish	M-22	3823 17th Avenue Southwest	Single-Family	Long-Term	67	69
Duwamish	M-21	3712 19th Avenue Southwest	Single-Family	Long-Term	72	75
Duwamish	ST-15	3711 19th Avenue Southwest	Single-Family	Short-Term	59	65
Duwamish	ST-16	3801 19th Avenue Southwest	Single-Family	Short-Term	58	62
Duwamish	ST-17	3719 20th Avenue Southwest	Single-Family	Short-Term	56	65
Duwamish	ST-18	2005 Southwest Charlestown Street	Single-Family	Short-Term	58	62
Duwamish	ST-19	3802 21st Avenue Southwest	Single-Family	Short-Term	60	62
Duwamish	ST-20	3801 22nd Avenue Southwest	Single-Family	Short-Term	60	62
Duwamish	M-20	3709 20th Avenue Southwest	Single-Family	Long-Term	72	75
Duwamish	M-23	3816 23rd Avenue Southwest	Single-Family	Long-Term	68	69
Duwamish	M-24	3856 23rd Avenue Southwest	Recording Studio	Long-Term	68	64
Delridge	M-17	4143 23rd Avenue Southwest	Single-Family	Long-Term	59	62
Delridge	M-16	4106 26th Avenue Southwest	Single-Family	Long-Term	52	54
Delridge	M-30	4040 26th Avenue Southwest	Multi-Family	Long-Term	63	64
Delridge	ST-13	4065 26th Avenue Southwest	Single-Family	Short-Term	55	62
Delridge	ST-14	2623 Southwest Yancy Street	Single-Family	Short-Term	58	64
Delridge	ST-6	4408 Delridge Way Southwest	Community Center	Short-Term	74	72
Delridge	ST-5	4501 Delridge Way Southwest	Park	Short-Term	74	Not Applicable
Delridge	M-15	4421 26th Avenue Southwest	Single-Family	Long-Term	51	53
Delridge	ST-8	Longfellow Creek Natural Area	Park	Short-Term	60	Not Applicable

Segment	Monitoring Location	Address	Land Use Type	Type of Measurement	Leq (Daytime-hour Leq in dBA)	Ldn (24-hour Ldn in dBA)
Delridge	ST-9	Longfellow Creak Natural Area	Park	Short-Term	59	Not Applicable
Delridge	ST-4	Longfellow Creek Legacy Trail	Park	Short-Term	47	Not Applicable
Delridge	M-25	2821 Southwest Yancy Street	Multi-Family	Long-Term	68	64
Delridge	ST-10	2819 Southwest Dakota Street	Single-Family	Short-Term	60	56
Delridge	ST-11	2851 Southwest Dakota Street	Single-Family	Short-Term	58	56
Delridge	M-13	2848 Southwest Genesee Street	Single-Family	Long-Term	60	60
Delridge	M-26	3000 Southwest Avalon Way	Multi-Family	Long-Term	72	70
Delridge	M-27	4009 32nd Avenue Southwest	Single-Family	Long-Term	60	57
Delridge	ST-12	4104 Southwest 32nd Avenue	Single-Family	Short-Term	56	57
Delridge	ST-3	4470 35th Avenue Southwest	Golf Course	Short-Term	70	67
West Seattle Junction	M-12	4143 32nd Avenue Southwest	Single-Family	Long-Term	53	56
West Seattle Junction	M-11	3225 Southwest Genesee Street	Single-Family	Long-Term	56	59
West Seattle Junction	M-10	4147 Fauntleroy Way Southwest	Single-Family	Long-Term	70	73
West Seattle Junction	M-9	3256 Southwest Avalon Way	Multi-family	Long-Term	67	68
West Seattle Junction	M-28	4403 37th Avenue Southwest	Single-Family	Long-Term	62	62
West Seattle Junction	M-5	4450 38th Avenue Southwest	Single-Family	Long-Term	66	68
West Seattle Junction	ST-2	4530 38th Southwest Avenue	Right-of-Way	Short-Term	69	67
West Seattle Junction	ST-1	4500 39th Avenue Southwest	Right-of-Way	Short-Term	58	55
West Seattle Junction	M-4	4700 38th Avenue Southwest	Fire Station	Long-Term	69	68
West Seattle Junction	M-29	4537 41st Avenue Southwest	Single-Family	Long-Term	67	61
West Seattle Junction	M-1	4023 Southwest Edmunds Street	Single-Family	Long-Term	62	62

5.2.2.1 SODO Segment

There are no sensitive receivers in the SODO Segment.

5.2.2.2 Duwamish Segment

Sound levels in the Duwamish Segment are governed almost entirely by traffic on the West Seattle Bridge and West Marginal Way Southwest, heavy truck traffic, heavy rail service, loading and unloading ships, and foghorns. The Ldn values in this segment ranged between 59 dBA and 75 dBA (M-20 to M-23 and ST-7) and peak hour Leq values ranged between 56 dBA and 72 dBA (M-20 to M-23 and ST-7 and ST-15 through ST-20). Median nighttime Leq levels ranged from 58 dBA to 67 dBA (M-20 to M-22).

5.2.2.3 Delridge Segment

The Delridge Segment Ldn values range between 53 dBA and 72 dBA (M-13 through M-27, M-30, and ST-3 to ST-14) and peak hour Leq values range between 47 dBA and 74 dBA (M-13 through M-27, M-30, and ST-3 to ST-14). Median nighttime Leq values ranged between 42 dBA and 54 dBA (M-13 through M-27 and M-30). Traffic on arterial roadways such as Delridge Way Southwest and Southwest Genesee Street were the dominant sound sources in this segment. Other contributing sound sources include smaller roadways, aircraft noise, industrial facilities, and trains.

5.2.2.4 West Seattle Junction Segment

The Ldn values in the West Seattle Junction Segment ranged from 55 dBA to 73 dBA (M-1 through M-12, M-28 through M-29, and ST-1 to ST-2) and peak hour Leq ranged from 53 dBA to 70 dBA (M-1 through M-12, M-28 through M-29, and ST-1 and ST-2). Median nighttime Leq values ranged from 48 dBA to 64 dBA (M-1 through M-12 and M-28 through M-29). Sound levels in this segment are primarily governed by traffic noise on nearby arterial roadways, such as Fauntleroy Way Southwest and 35th Avenue Southwest.

5.3 Vibration Measurements

The vibration measurements conducted for the assessment include an ambient vibration survey and vibration propagation measurements. The ambient vibration measurement survey documents existing vibration levels near existing rail lines and at highly vibration-sensitive buildings. The vibration propagation measurements are used to quantify how efficiently vibration travels through the soil and are used in the vibration prediction model. The vibration propagation measurements are completed at representative sites throughout the study area.

5.3.1 Ambient Vibration Survey (Representative Sites)

The FTA Guidance Manual (2018) recommends that where there are existing rail lines, existing vibration conditions be considered when determining vibration impact criteria for a new transit project. Both the existing vibration levels and the frequency with which the existing rail corridor is used are factors in determining the appropriate impact criteria.

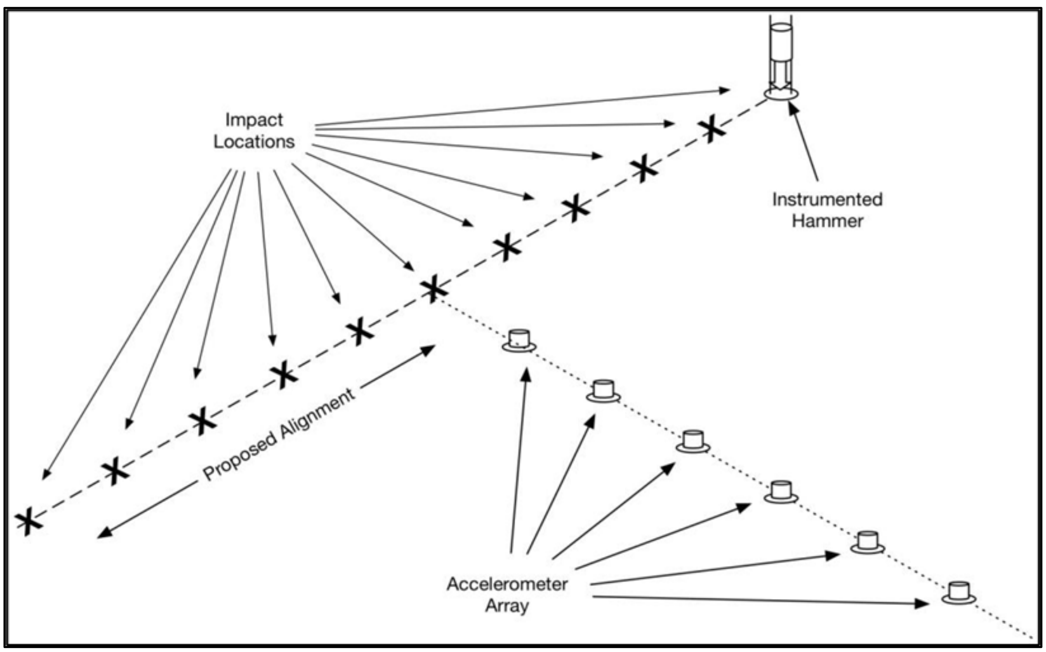
There are existing freight operations in West Seattle, but they are infrequently used or beyond the screening distance of the vibration-sensitive receivers. An existing vibration measurement was completed at Harbor Island Machine Works, a Category 1 vibration-sensitive receiver. The results of the ambient vibration measurement are shown in Attachment N.3H, Vibration Analysis of Category 1 Uses and Special Buildings.

5.3.2 Vibration Propagation Tests

A vibration propagation test is used to determine the line source transfer mobility, which is a measure of how efficiently vibration travels through the earth. The field test procedure for determining the line source transfer mobility is shown schematically on Figure 5-8 for at-grade or surface sites. The measurement consists of dropping a heavy weight on to the ground surface and measuring the force imparted into the ground and the vibration response at sensors at several distances from the weight.

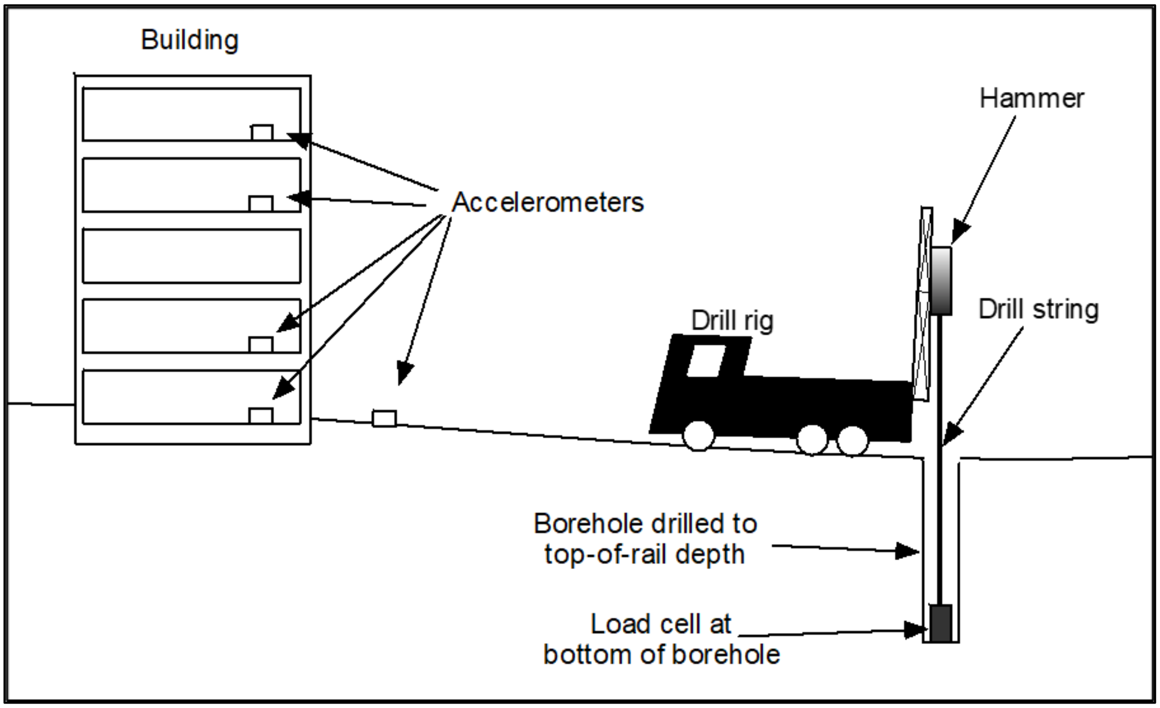
As shown on Figure 5-8, the weight is dropped at a line of discrete impact points to approximate the distributed line source of a light rail vehicle. The accelerometer sensors that measure the vibration response are placed in a line perpendicular to the line of impact points. The number of accelerometers and their distances from the impact line vary at each test site depending on field conditions.

Figure 5-8. Schematic of Surface Vibration Propagation Test Procedure



For tunnel and borehole sites, an impact hammer was used to generate vibration at the bottom of a borehole. Typically, data were collected at three depths: 10 feet above the depth of the track, at the depth of the track, and 10 feet below the depth of the track. The measured data from the three test depths were extrapolated to account for the length of the train instead of using a line of impact points as with the surface measurements. The accelerometer sensors that measure the vibration response were placed on the surface in a line extending away from the borehole. At some measurement locations, sensors were also placed inside of the building to measure the building response. Figure 5-9 shows a schematic of the borehole vibration propagation test procedure.

Figure 5-9. Schematic of Borehole Vibration Propagation Test Procedure



The vibration propagation test sites were selected based on a review of aerial photographs and a windshield survey of land uses. Vibration propagation tests have been completed at seven sites in the project study area. The results of the vibration propagation test are the line source transfer mobility and the coherence. Coherence is a measure of the quality of the line source transfer mobility results and varies between 0 and 1. A coherence value close to 1 indicates that the vibration response and the force generated by the dropped weight are closely related. A coherence less than about 0.2 indicates a relatively weak relationship between the exciting force and the vibration response. Low coherence results may occur when the ambient vibration is relatively high, the distance between the dropped weight and the sensor are relatively far, or when the soil is a poor transmitter of vibration at a particular frequency. Most measurement sites have coherence below 0.2 at frequencies less than 20 hertz, indicating the soil is a relatively poor transmitter of vibration at low frequencies. Many measurement sites have low coherence for the farthest sensor locations.

Higher line source transfer mobility levels indicate that vibrations are transmitted more efficiently through the soil. The frequency range with the highest line source transfer mobility values is important because it indicates the frequency range where vibration is transmitted most efficiently. If the frequency range with high line source transfer mobility values coincides with the frequency range in which the train produces the most energy, it would result in higher vibration at sensitive receivers. In the project area, surface propagation tests were completed at four sites in residential areas and at the Category 1 sensitive receiver Harbor Island Machine Works. Borehole propagation tests were completed at two sites in residential areas. A summary of the vibration propagation test sites and sensor locations is provided in Table 5-2, and a map of the test sites is shown on Figures 5-5 through 5-7. Surface vibration propagation test sites are labeled with letters and borehole propagation test sites are labeled with numbers. Photographs and aerial maps of each test site are provided in Attachment N.3B. Detailed vibration propagation measurement results, including the best-fit coefficients for the line source transfer mobilities, are provided in Attachment N.3C, Vibration Propagation Measurement Results.

Table 5-2. Summary of Vibration Propagation Test Sites

Segment	Test Site	Location	Sensor Positions (in feet or by location)
Duwamish	V-E (surface)	Harbor Island Machine Works, 3431 11th Avenue Southwest	25, 50, 75, 100, 125, 150
Duwamish	V-D (surface)	Bike path at 22nd Avenue Southwest at West Seattle Bridge	29, 52, 75, 100, 125, 160, 200
Delridge	V-C (surface)	Southwest Dakota Street at 25th Avenue Southwest	25, 50, 75, 100, 125, 150, 195
West Seattle Junction	V-B (surface)	Southwest Genesee Street at 32nd Avenue Southwest	25, 50, 75, 100, 125, 150, 200
West Seattle Junction	V-3 (borehole)	Alley at Southwest Genesee Street and 35th Avenue Southwest	0, 45, 75, 105, 123, 150, 200
West Seattle Junction	V-2 (borehole)	39th Avenue Southwest at Southwest Genesee Street	0, 25, 50, 75, 100, 150, 200
West Seattle Junction	V-A (surface)	Alley on 41st Avenue Southwest, north of Southwest Alaska Street	25, 50, 75, 100, 125, 150

Figures 5-10 and 5-11 show the measured vibration propagation test results at or close to 100 feet for surface measurement sites and at or close to 150 feet for borehole measurement sites, respectively. For the surface sites, the line source transfer mobility is presented, and for borehole sites, the point source transfer mobility is presented because it is not possible to measure at a line of impact points. The point source transfer mobility has lower amplitudes compared to the line source transfer mobility.

Observations from the vibration propagation test results were as follows:

- Surface sites:
  - Site V-E shows high line source transfer mobility levels at frequencies below 40 hertz and lower line source transfer mobility levels above 40 hertz. This site was on Harbor Island, which is composed of reclaimed land. The data from this site are only applied to Harbor Island Machine Works, the sensitive receiver where the data were collected.
  - In general, the surface sites show the highest line source transfer mobility levels in the 30- to 60-hertz range, with levels decreasing at higher frequencies.
  - The data show generally good agreement across different measurement sites with the exception of Site V-E. Site V-B does show more efficient vibration propagation at 40- and 50-hertz compared to the other sites.
- Borehole sites:
  - At borehole vibration propagation test sites, the transfer mobilities generally have flatter spectra than the surface sites. This generally results in lower levels in the 30- to 60-hertz range, but higher levels at higher frequencies.
  - The data shows generally good agreement at the two borehole measurement sites.

Figure 5-10. Measured Line Source Transfer Mobility at 100 Feet for Surface Sites

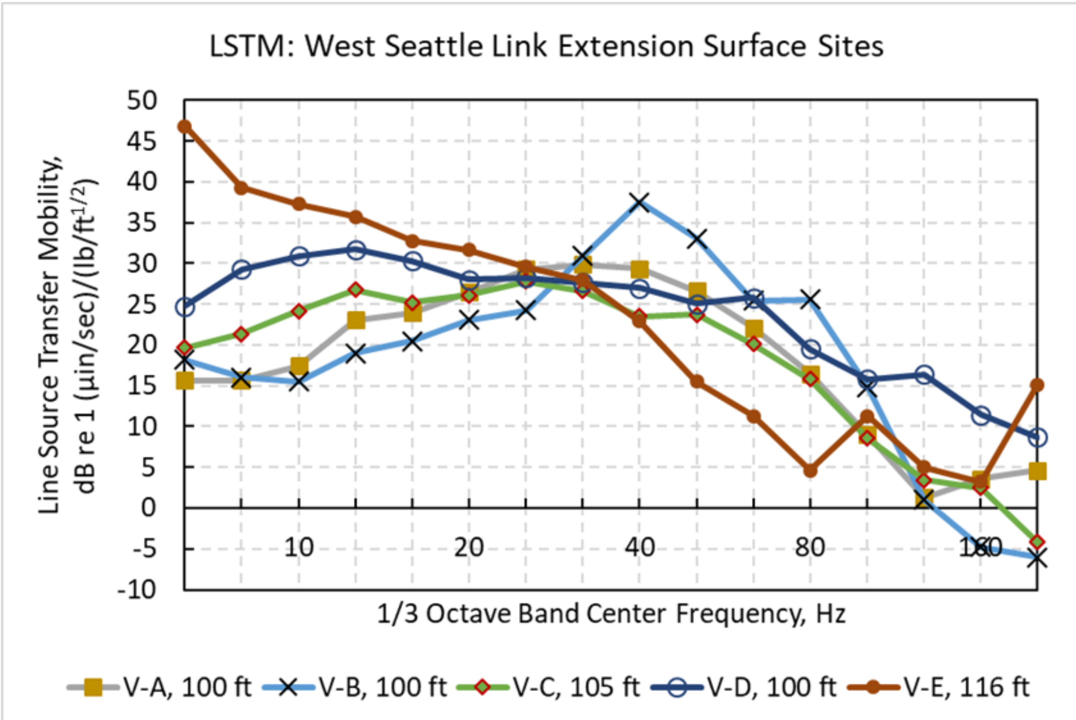
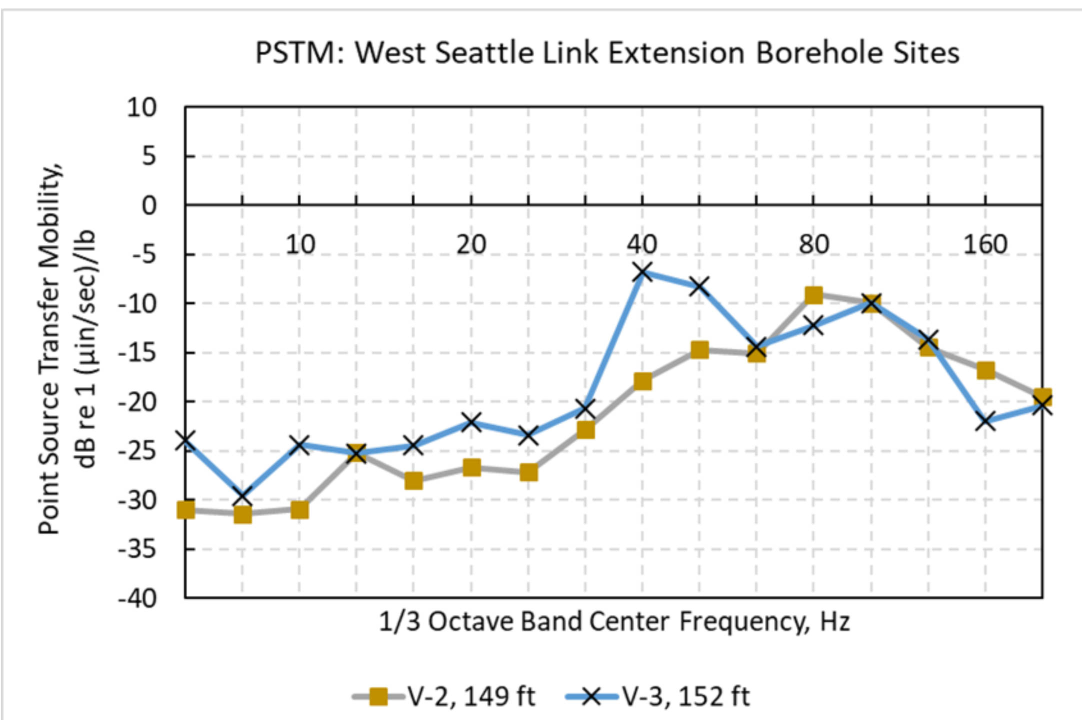


Figure 5-11. Measured Point Source Transfer Mobility at 150 Feet for Borehole Sites



6 IMPACT ASSESSMENT

Sound Transit performed a detailed noise and vibration impact assessment based on the criteria discussed in Chapter 3, Noise and Vibration Impact Criteria, using the methods and projections described in Chapter 4, Noise and Vibration Impact Analysis Assumptions and Methods, of this report. For areas with potential noise or vibration impacts, mitigation measures are evaluated and proposed as described in Chapter 7, Noise and Vibration Mitigation Measures. Potential noise and vibration impacts from light rail transit operations according to the FTA Guidance Manual (2018) are provided in the following sections. An assessment of construction noise levels was also performed, and is described in Section 6.2, Construction Noise Impacts.

Assessment details are provided in the following attachments:

- Attachment N.3A: Noise Measurement Data, Site Details and Photographs
- Attachment N.3B: Vibration Measurement Site Photographs
- Attachment N.3C: Vibration Propagation Measurement Results
- Attachment N.3D: Maps of Noise Impact Assessment
- Attachment N.3E: Maps of Vibration Impact Assessment
- Attachment N.3F: Tables of Noise Predictions
- Attachment N.3G: Tables of Vibration Predictions
- Attachment N.3H: Vibration Analysis of Category 1 Uses and Special Buildings

Summary discussions of the results are provided in the following sections.

6.1 Operational Noise Impacts

6.1.1 Transit Noise Impact Analysis

This section provides the results of the detailed noise analysis for the West Seattle Link Extension. The study area for the West Seattle Link Extension is based on measured noise levels of the existing fleet of Sound Transit light rail vehicles, operational schedule, and train speeds, and is large enough to capture all potential noise impacts from system operations. System operations includes all light rail-related noise sources (wayside noise, bells, crossovers) ancillary facilities, and identification of areas with potential wheel squeal. Based on this information, the analysis includes noise-sensitive properties within at least 500 feet of the track alignments. This amounts to over 70 analysis locations in the Duwamish Segment, over 450 in Delridge, and nearly 900 in the West Seattle Junction area. The locations analyzed include single- and multi-family residences, fire stations, schools, daycares, a recording studio, parks, and other FTA noise-sensitive land uses.

Figures displaying the locations of noise impacts and tables with detailed noise analysis information are provided in Attachment N.3D and Attachment N.3F.

6.1.1.1 No Build Alternative

Under the No Build Alternative, traffic noise levels would continue to be dominated by major and minor arterial roadways, aircraft over flights, unrelated construction projects, and commercial, industrial, and residential activities. Because there would be no light rail construction or operations, no light rail-related noise impacts are predicted.

6.1.1.2 Build Alternatives

The noise impacts are summarized by alternative and include moderate and severe impacts for each of the three FTA categories. A general discussion of impacts for each of the alternatives is also included. Detailed information on the impacts are provided graphically on area maps in Attachment N.3D and tables of the noise projections by receiver are provided in Attachment N.3F.

SODO Segment

There are no FTA noise-sensitive properties in the SODO Segment; therefore, no operational noise analysis was performed.

Duwamish Segment

A summary of the noise impacts for the Duwamish Segment is shown in Table 6-1 and on Figure 6-1. Detailed figures displaying the locations of noise impacts and tables with detailed noise analysis information are provided in Attachments N.3D and N.3F.

Table 6-1. Summary of Light Rail Noise Impacts by Alternative for the Duwamish Segment

Alternatives and Design Options	Category 1 Noise Impacts	Category 2 Moderate Noise Impacts	Category 2 Severe Noise Impacts	Category 3 Noise Impacts	Total Noise Impacts
Preferred South Crossing Alternative (DUW-1a)	**0**	**25 to 45**	**1 to 6**	**0**	**29 to 47**
South Crossing South Edge Crossing Alignment Option (DUW-1b)	0	34	1	0	35
North Crossing Alternative (DUW-2)	0	1	0	0	1

Notes:

The numbers presented are the number of units, counted by individual residences, including individual units of multi-family structures, and number of structures for other uses, like schools, churches and parks. Category 2 parcels are evaluated with the 24-hour Ldn and Category 1 and 3 are evaluated with the peak hour Leq.

Ranges reflect differences from connecting to different alternatives in adjacent segments. The total impacts are based on individual alternatives and connection options and not the high and low of each impact type shown in the table.

The Duwamish Segment includes the area between South Forest Street at the east end of the segment and Southwest Charlestown Street at the west end of the segment.

Preferred Alternative DUW-1a and Option DUW-1b would have the most overall impacts in the Duwamish Segment. These alternatives could connect to any of the SODO and Delridge segment alternatives. Noise impact differences between the two alternatives are affected by five factors – retained-cut segments, receiver elevation, track elevation, crossovers, and track location across the Duwamish Waterway. Alternative DUW-2 would have the fewest noise impacts of all the Duwamish Segment alternatives. All alternatives except Alternative DUW-2 transition to a retained-cut section along the West Duwamish Greenbelt.

The alignment for Alternative DUW-2 would be farther north than the other alternatives (north of the West Seattle Bridge) and far enough away from residential housing to not cause noise impacts in the Pigeon Point or Riverside neighborhoods.

Each of the Duwamish Segment alternatives would have a noise impact at Fire Station 14 due to proximity to the guideway and crossovers.

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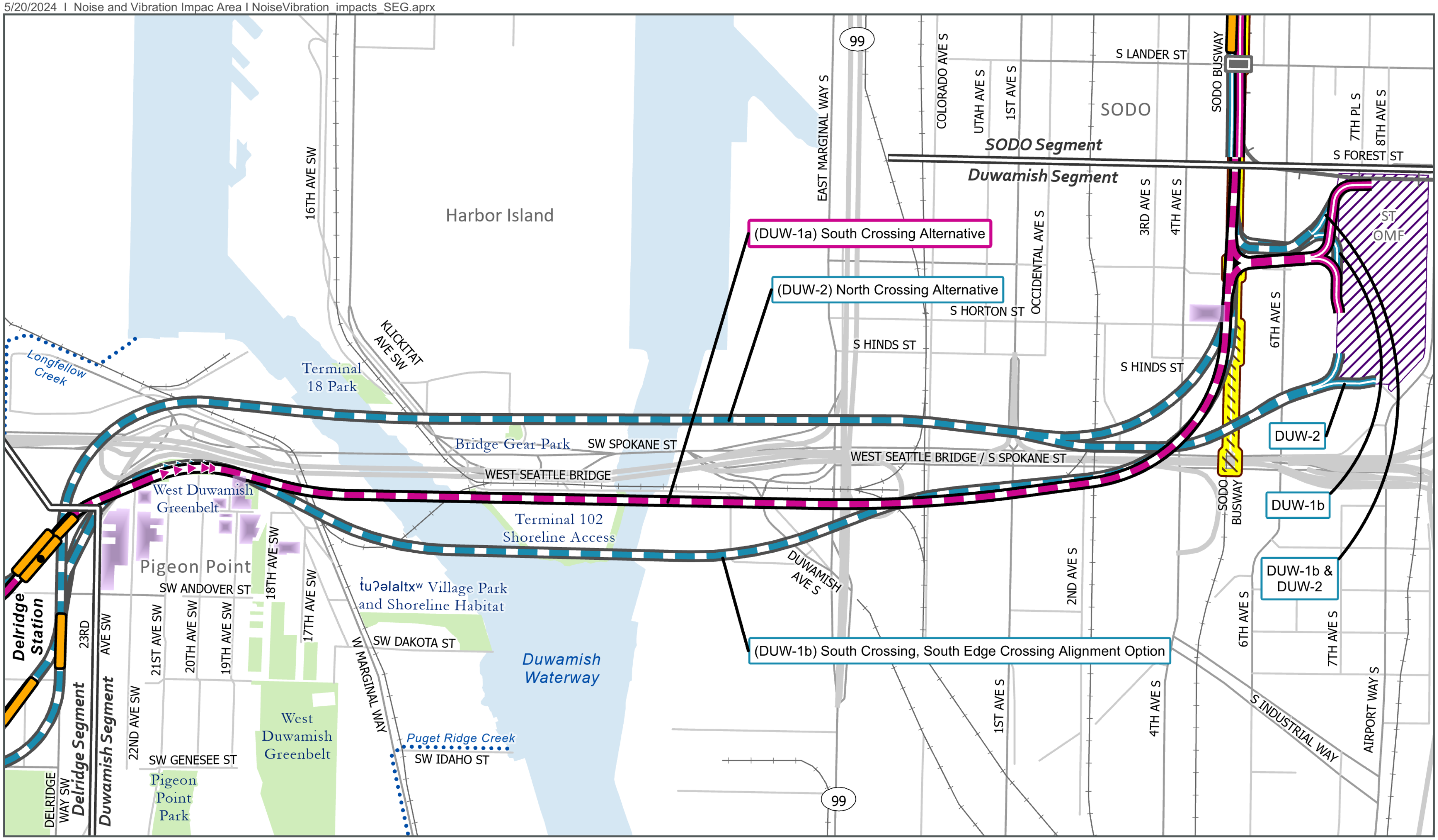


Source: City of Seattle, King County (2023).

Preferred Alternative
- Elevated
- Retained Cut
- At-Grade

Other Alternatives
- Elevated
- Retained Cut
- At-Grade

Station (● *Indicates Preferred Alternative*)
- New

- Segment Line
- Existing Link Light Rail
- Railroad
- SODO Busway
- Proposed Overpass
- Sound Transit Operations and Maintenance Facility (ST OMF)
- Piped Stream
- Park
- Area of Noise Impact

FIGURE 6-1
Noise Impacts (before mitigation)
Duwamish Segment

West Seattle Link Extension

0 500 1,000 Feet N

Preferred South Crossing Alternative (DUW-1a)

Preferred Alternative DUW-1a, when connecting to Preferred Option DEL-6b and Alternative DEL-7, would have more overall severe noise impacts than the other Duwamish Segment Build Alternatives. A severe impact was identified at Fire Station 14 at 3224 4th Avenue South. The remaining severe impacts were identified at single-family homes along the north end of 22nd Avenue Southwest, where homes would have minimal shielding from light rail noise.

When connecting to Preferred Option DEL-6b and Alternative DEL-7, moderate noise impacts were identified at the following locations:

- A cluster of single-family residences along 17th Avenue Southwest, where the homes would have line of sight to the new light rail structure
- Between 19th Avenue Southwest and 21st Avenue Southwest along Southwest Charlestown Street, where the alignment would be elevated, approaching Pigeon Point
- Along the north end of 22nd Avenue Southwest, where residences uphill from the guideway will have minimal or no acoustical shielding

Fire Station 36 at 3600 23rd Avenue Southwest would not have a noise impact because of the high existing noise levels and because of the distance and shielding from the elevated structure. Noise from light rail operations on the guideway would be shielded from impacting Seattle Fire Station 36 by the structure itself. The guideway would act as a noise barrier and would effectively block noise from going downward toward the Fire Station 36 building.

When connecting to Alternative DEL-1a and Option DEL-1b, there would be fewer noise impacts due to higher track elevations. However, connections to Alternative DEL-2a and Option DEL-2b would have a lower track elevation, resulting in impacts more similar to Preferred Alternative DUW-1a when connecting to Preferred Option DEL-6b and Alternative DEL-7. When connecting to Alternative DEL-3 or Alternative DEL-4, Preferred Alternative DUW-1a would have fewer moderate noise impacts due to the alignment being farther from single- and multi-family residences along 22nd Avenue Southwest and not having a crossover on Pigeon Point.

When connecting to Alternative DEL-5 or Alternative DEL-6a, Preferred Alternative DUW-1a would have fewer predicted noise impacts than the connections with Alternative DEL-3 or Alternative DEL-4. The alignment would be partially shielded by a retained cut along Pigeon Point when connecting to Alternative DEL-5 and due to the aerial track when connecting to Alternative DEL-6a.

Following Sound Transit policy and the discussion in Section 4.1.1.5, Operations Plan, the Duwamish Segment was reviewed for curves with the potential for wheel squeal. Under Preferred Alternative DUW-1a, there would be several curves located primarily near the existing Operations and Maintenance Facility Central. The first two curves with radii of 125 feet and 160 feet would be at the north and south of the entrance to the Operations and Maintenance Facility Central, followed by 150 feet curves just as the tracks branch off to the facility's connections. The northern connection would have one curve at 150 feet with one additional curve radii at the tail end of 140 feet. The south connection only would have two curves both with a radius of 150 feet. To the southwest of the facility, there would be one more curve before crossing the Duwamish Waterway with a 1,150-foot radius by 4th Avenue South, which may impact Fire Station 14. West of the Duwamish Waterway crossing there would be only one curve with a radius less than 1,250 feet; this curve would have a 950-foot radius and would be north of 20th Avenue Southwest near the West Seattle Bridge, by single- and multi-family residences. The majority of crossovers for Preferred Alternative DUW-1a would be for Operations and Maintenance Facility Central access. They would consist of single and double crossovers at the facility's entrances and north and south of the connection guideways.

While most crossovers would be within commercial/industrial areas, the crossovers at the south entrance would be close to Fire Station 14 and therefore were included in the analysis. One additional crossover would be located north of 22nd Avenue Southwest just before transitioning to the Delridge Segment when connecting to Preferred Option DEL-6b and Alternative DEL-7. The crossover has the potential to result in noise impacts on residences in this area. When connecting to Alternative DEL-5 and Alternative DEL-6a the crossover would be located north of 21st Avenue Southwest. There are no crossovers in the Duwamish Segment Pigeon Point area when connecting to Alternative DEL-1a, Option DEL-1b, Alternative DEL-2a, Option DEL-2b, Alternative DEL-3, or Alternative DEL, because the crossover is located in the Delridge Segment under these alternatives.

South Crossing South Edge Crossing Alignment Option (DUW-1b)

Option DUW-1b would have one severe noise impact at Fire Station 14. Moderate impacts that would affect single-family and multi-family residences were identified at the same areas as described under Preferred Alternative DUW-1a. However, Option DUW-1b would have slightly more noise impacts at residences on the east side of Pigeon Point than Preferred Alternative DUW-1a due to the southern alignment across Harbor Island.

Option DUW-1b would have the same curves and crossovers at the existing Operations and Maintenance Facility Central as Preferred Alternative DUW-1a and only one curve with the potential for wheel squeal in the Pigeon Point area near the West Duwamish Greenbelt. This curve would have a 950-foot radius, and would be north of 20th Avenue Southwest near the West Seattle Bridge by single- and multi-family residences. There would be no crossovers in the Pigeon Point area because the crossover would be located in the Delridge Segment for these alternatives.

North Crossing Alternative (DUW-2)

Alternative DUW-2 would have the least noise impacts for the Duwamish Segment. It would have no severe noise impacts and one moderate noise impact at Fire Station 14. It would not have impacts on any residential properties in the Pigeon Point area.

Most curves and crossovers for the Alternative DUW-2 would be for the Operations and Maintenance Facility Central access. This would include several curves, a 125-foot-radius curve followed by three more curves at 150-foot, 300-foot, and 130-foot radii. There would also be a 1,250-foot-radius curve between the north and south facility access near 4th Avenue South, which may affect Fire Station 14. The south facility access would have six curves with three of those curves having a radius between 1,100 and 1,000 feet. The remaining south curves would be at the far east end of the main guideway and have curve radii between 200 and 250 feet. There would be additional tight-radius curves associated with the connection to the Operations and Maintenance Facility Central. Alternative DUW-2 would have one more curve after crossing west over the Duwamish Waterway between West Marginal Way Southwest and Chelan Avenue Southwest with a 900-foot curve radius, but this curve would be in a commercial and industrial area.

Duwamish Segment Bus Operations

Bus operations in the Duwamish Segment would remain on existing roadways; therefore, no noise analysis for buses was required.

Delridge Segment

Noise impacts for the Delridge Segment are shown in Table 6-2 and on Figure 6-2. Some of the impacts in this segment are in the Duwamish Segment; however, these impacts are caused by the alignment within the Delridge Segment. Impacts shown in Table 6-2 assume a connection to Preferred Alternative DUW-1a in the Duwamish Segment. Impacts would be reduced when connecting to Alternative DUW-2. Detailed figures displaying the locations of noise impacts and tables with detailed noise analysis information are provided in Attachments N.3D and N.3F.

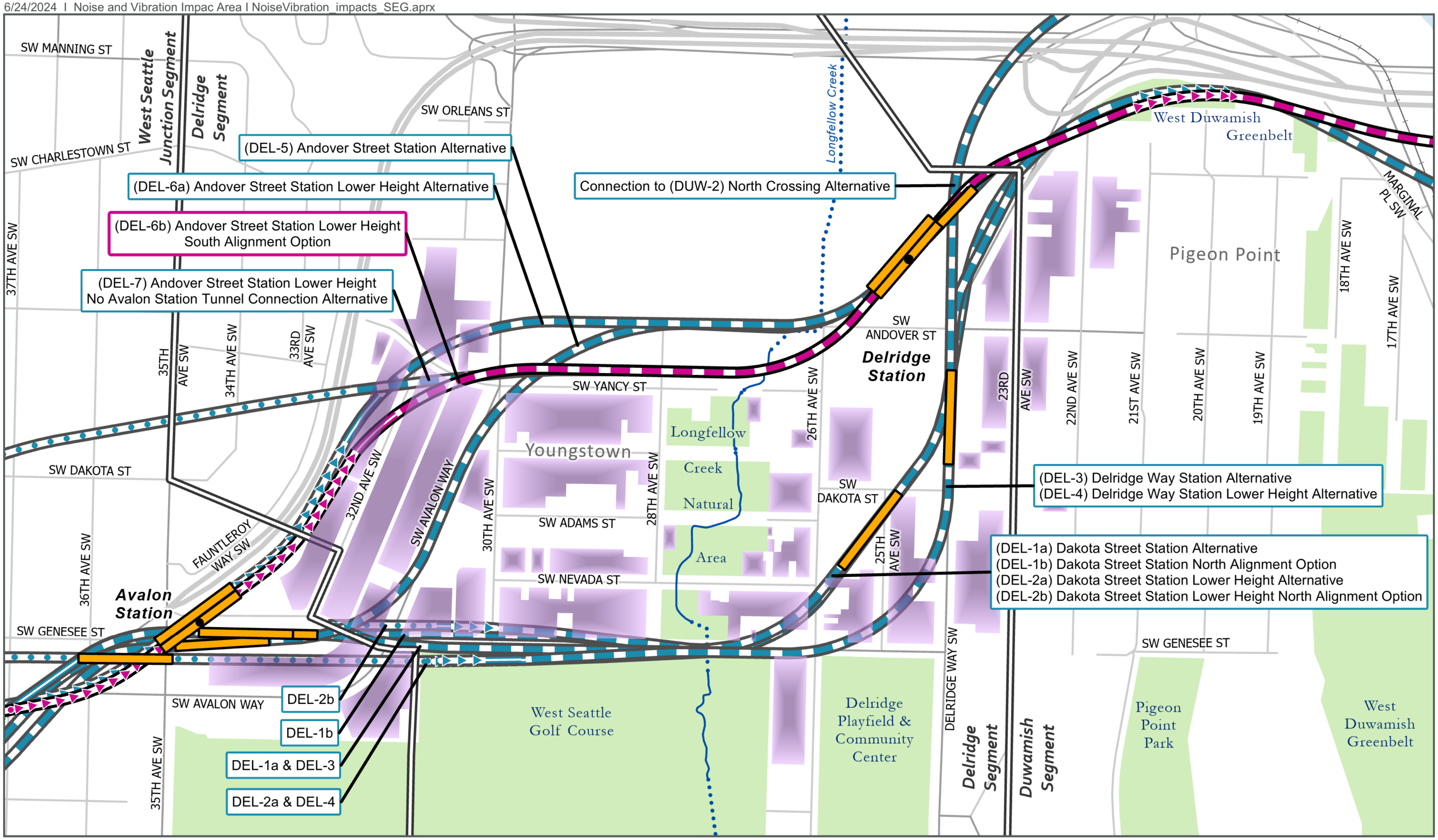
The Delridge Segment generally includes the area between Southwest Charlestown Street (west of Delridge Way Southwest) at the east end of the segment and 31st Avenue Southwest at the west end of the segment. Alternative DEL-6a would have the fewest overall noise impacts because it would be farther from most residences, followed by Preferred Option DEL-6b, while Alternatives DEL-1a, DEL-3, DEL-4, and DEL-5 would have the most overall noise impacts because they are closest to the greatest number of residences. Alternative DEL-5 and Alternative DEL-7 would have the most severe noise impacts.

Preferred Option DEL-6b and Alternative DEL-7 would have similar alignments north of Southwest Yancy Street, where Preferred Option DEL-6b and Alternative DEL-7 would be just north of Southwest Yancy Street. Preferred Option DEL-6b would turn south near 32nd Avenue Southwest before transitioning to a retained cut near the West Seattle Junction Segment. Alternative DEL-7 would continue slightly southwest across the West Seattle Bridge before going into a tunnel. Due to speed restrictions along the curve west of Southwest Avalon Way, Preferred Option DEL-6b would have slightly slower speeds, and thereby lower noise levels, than Alternative DEL-7.

Table 6-2. Summary of Light Rail Noise Impacts by Alternative for the Delridge Segment

Alternatives and Design Options	Category 1 Noise Impacts	Category 2 Moderate Noise Impacts	Category 2 Severe Noise Impacts	Category 3 Noise Impacts	Total Noise Impacts
Preferred Andover Street Station Lower Height South Alignment Option (DEL-6b)	**0**	**156**	**5**	**0**	**161**
Dakota Street Station Alternative (DEL-1a)	1	228 to 240	5 to 6	0	234 to 247
Dakota Street Station North Alignment Option (DEL-1b)	1	203	14	0	218
Dakota Street Station Lower Height Alternative (DEL-2a)	1	218	22	0	241
Dakota Street Station Lower Height North Alignment Option Alternative (DEL-2b)	1	154	23	0	178
Delridge Way Station Alternative (DEL-3)	1	242	2	0	245
Delridge Way Station Lower Height Alternative (DEL-4)	1	217	28	0	246
Andover Street Station Alternative (DEL-5)	0	208	43	0	251
Andover Street Station Lower Height Alternative (DEL-6a)	0	55	13	0	68
Andover Street Station Lower Height No Avalon Station Tunnel Connection Alternative (DEL-7)	0	186	42	0	228

Note: The numbers presented are the number of units, counted by individual residences, including individual units of multi-family structures, and number of structures for other uses, like schools, churches and parks. Category 2 parcels are evaluated with the 24-hour Ldn and Category 1 and 3 are evaluated with the peak hour Leq.



Source: City of Seattle, King County (2023).

Preferred Alternative
- Elevated
- Tunnel
- At-Grade
- Retained Cut

Other Alternatives
- Elevated
- Tunnel
- At-Grade
- Retained Cut

Station (● *Indicates Preferred Alternative*)
- New

- Segment Line
- Railroad
- Stream
- Piped Stream
- Park
- Area of Noise Impact

FIGURE 6-2
Noise Impacts (before mitigation)
Delridge Segment

West Seattle Link Extension

Both Alternative DEL-1a and Option DEL-1b would share similar track alignment and elevation except along Southwest Genesee Street between 28th Avenue Southwest and Southwest Avalon Way, where Alternative DEL-1a would be on the south side of the Southwest Genesee Street right-of-way while Option DEL-1b would shift to the north side of Southwest Genesee Street.

Alternative DEL-2a and Option DEL-2b would have similar alignments at lower elevations than Alternative DEL-1a and Option DEL-1b. Under Alternative DEL-2a, the guideway would be along the northern edge of the West Seattle Golf Course at 4470 35th Avenue Southwest, south of Southwest Genesee Street, while Option DEL-2b runs north of Southwest Genesee Avenue. Both alternatives would enter tunnel portals east of the West Seattle Junction Segment.

Both Alternatives DEL-3 and DEL-4 would travel farther south along Delridge Way than Alternative DEL-1a, Option DEL-1b, Alternative DEL-2a, and Option DEL-2b. While they both would have different guideway elevations, they would share similar alignments until Southwest Genesee Street between 28th Avenue Southwest and Southwest Avalon Way. Alternative DEL-3 would run along the south side of the Southwest Genesee Street right-of-way, while Alternative DEL-4 would travel along the northern edge of the West Seattle Golf Course, south of Southwest Genesee Street, just before the West Seattle Junction Segment.

Alternative DEL-5 and Alternative DEL-6a would both be along Southwest Andover Street. Though they would have different guideway elevations, their alignments would be similar until they reach the intersection of 28th Avenue Southwest and Southwest Andover Street. From there, Alternative DEL-5 would turn south to travel along Southwest Avalon Way and Alternative DEL-6a would continue west, turning south just east of the West Seattle Bridge before entering a retained cut near the West Seattle Junction Segment.

Preferred Andover Street Station Lower Height South Alignment Option (DEL-6b)

Preferred Option DEL-6b could connect to all Build Alternatives in the Duwamish Segment and to Preferred Option WSJ-5b and Alternative WSJ-5a in the West Seattle Junction Segment.

The only severe noise impacts were identified at five single-family residences along the north end of 23rd Avenue Southwest where the alignment would transition to the south, west of 23rd Avenue Southwest. The distances from these residences to the nearest station range from 30 feet to 165 feet.

Moderate impacts would be felt throughout the alignment corridor. On the east side of this segment, near the Delridge Station, moderate noise impacts were identified at Youngstown Flats, a five-story apartment building at 4040 26th Avenue Southwest, on the corner of Southwest Dakota Street and 26th Avenue Southwest, in close proximity to the guideway and station. The train-mounted warning bells at the Delridge Station would contribute to a number of the moderate noise impacts identified.

Other moderate noise impacts are found at most first-row single- and multi-family residences along Southwest Yancy Street, including housing for Transitional Resources (a non-profit behavioral health center and supportive housing facility), where there is no acoustical shielding. The guideway is approximately 100 feet from many of the residential buildings. Some second- or third-story second-row residences would also have moderate impacts when there is no acoustical shielding from first-row buildings.

The west end of the alignment has moderate impacts at most first-row residences along 32nd Avenue Southwest, where the guideway runs east of the West Seattle Bridge before transitioning to the West Seattle Junction Segment. Impacts were also identified near the intersection of Southwest Avalon Way and Southwest Andover Street, where the guideway begins its transition south and east of the West Seattle Bridge. Residences with noise impacts in this area include portions of the Transitional Resources buildings along Southwest Avalon Way.

A noise analysis was performed at the frequent use areas in Longfellow Creek Natural Area and no noise impacts were identified.

Following Sound Transit policy and the discussion in Section 4.1.1.6, Wheel Squeal and Wheel-Flanging Noise, the Delridge Segment was reviewed for curves with the potential for wheel squeal. Preferred Option DEL-6b would have a 625-foot-radius curve north of Delridge Station on Delridge Way Southwest near the intersection with Southwest Charlestown Street. South of Delridge Station, a 675-foot-radius curve and a 625-foot-radius curve would be near the intersection of Southwest Andover Street and 26th Avenue Southwest. There would be one additional curve of 950-foot radius south of the intersection of Southwest Andover Street and 32nd Avenue Southwest.

There would be no crossovers in the Delridge Segment under Preferred Option DEL-6b.

Dakota Street Station Alternative (DEL-1a)

Alternative DEL-1a could connect to all Build Alternatives in the Duwamish Segment and Alternative WSJ-1, Alternative WSJ-2, and Alternative WSJ-4 in the West Seattle Junction Segment.

Alternative DEL-1a could connect to Preferred Alternative DUW-1a in the Duwamish Segment and Alternative WSJ-2 in the West Seattle Junction Segment. The range of impacts for Alternative DEL-1a would depend on the connection in the Duwamish Segment. When connecting to Preferred Alternative DUW-1a, Alternative DEL-1a would have the most impacts. When connecting to Alternative DUW-2, it would have the least moderate noise impacts predicted for the area north of the station. This alternative would have less severe noise impacts than other Delridge Segment alternatives except Preferred Option DEL-6b, Alternative DEL-3, and Alternative DEL-6a.

Most of the severe noise impacts would be found near the east end of the alignment, which would be in close proximity to the guideway and station. Severe noise impacts would affect single-family residences on 23rd Avenue Southwest near Southwest Andover Street and at the southeast corner of 26th Avenue Southwest and Southwest Nevada Street along with upper-floor units at a multi-family complex, The Edge Apartments at 3101 Southwest Avalon Way. Single-family residences along Delridge Way Southwest, Southwest Andover Street, 22nd Avenue Southwest, and 23rd Avenue Southwest are predicted to have moderate noise impacts due to proximity to the guideway and a double crossover. The station would contribute to a number of moderate noise impacts due to noise from the train-mounted warning bells.

As described in Chapter 5, Affected Environment, there is one building in the Delridge Segment that meets the requirements for analysis under the FTA Category 1 criteria. Secret Studio Records/Studio 1208, on the southwest corner of 23rd Avenue Southwest and Southwest Andover Street, is a wooden-framed structure built in 1916 that has been converted to a recording studio and is predicted to have a moderate noise impact.

A cluster of moderate noise impacts were identified at The Edge Apartments. Noise impacts at residences along 23rd Avenue Southwest and Southwest Andover Street would be from a combination of noise from the light rail operations and a nearby crossover.

West of the station, lower ambient noise levels would result in a lower impact criterion and nearly all the residences in between Southwest Adams Street and Southwest Nevada Street west of 26th Avenue Southwest are predicted to have moderate noise impacts. As the alignment would make its way onto Southwest Genesee Street, single- and multi-family residences on Southwest Nevada Street between 26th Avenue Southwest and 28th Avenue Southwest would have moderate noise impacts from a combination of low existing ambient noise levels, close proximity to the guideway, and noise from the station.

A noise analysis was performed at the frequent use areas in Longfellow Creek Natural Area and no noise impacts were identified.

Three curves at 1,250 feet or less were identified under Alternative DEL-1a. The first curve, with a 625-foot radius, would be along Delridge Way Southwest between Southwest Dakota Street and Southwest Andover Street. Another 625-foot-radius curve would be just north of Southwest Genesee Street and slightly west of the intersection with 26th Avenue Southwest. The final curve, at a 1,250-foot radius, would be at the west end of the alternative on Southwest Genesee Street between 30th Avenue Southwest and Southwest Avalon Way.

Under the alternative, there would be one crossover along Delridge Way Southwest at the intersection with Southwest Andover Street. The crossover would be near single- and multi-family residences and was included in the light rail analysis. The crossover would contribute to noise impacts identified in this area.

Dakota Street Station North Alignment Option (DEL-1b)

Option DEL-1b could connect to all Build Alternatives in the Duwamish Segment and Alternative WSJ-1, Alternative WSJ-2, and Alternative WSJ-4 in the West Seattle Junction Segment.

Option DEL-1b shares a similar alignment and track elevation with Alternative DEL-1a in the northeast end of the segment. However, Option DEL-1b would transition to the north side of Southwest Genesee Street just east of 28th Street Southwest.

There would be several severe noise impacts with this alternative. Severe impacts would occur at single-family residences along Southwest 23rd Avenue and Southwest Andover Street and along 26th Avenue Southwest and Southwest Nevada Street. The remaining severe noise impacts would be at the west end of the alternative, and would affect multi-story apartment buildings on the northwest and southwest corner of Southwest Genesee Street and Southwest Avalon Way. All of these apartments would be in close proximity to the guideway as it would be approaching Avalon Station.

Moderate noise impacts were also identified for Option DEL-1b. Youngstown Flats apartments would receive the largest cluster of moderate noise impacts, due to its close proximity to the elevated guideway and the station. Moderate impacts would occur at single- and multi-family residences along the west slope of Pigeon Point, along 22nd Avenue Southwest and 23rd Avenue Southwest. Moderate impacts were also identified south of Southwest Andover Street, along Delridge Way Southwest and 23rd Avenue Southwest at single- and multi-family residences.

Additional moderate noise impacts would occur east of the station along 25th Avenue Southwest at Southwest Genesee Street and along Delridge Way Southwest south of Southwest Dakota Street. The alternative would travel on Southwest Genesee Street where single- and multi-family residences on Southwest Nevada Street between 26th Avenue Southwest and 28th Avenue Southwest would have moderate noise impacts due to the close proximity to the guideway, noise from the station, and lower existing noise levels.

Option DEL-1b would have slightly fewer moderate noise impacts at single- and multi-family residences on Southwest Nevada Street between 30th Avenue Southwest and 28th Avenue Southwest than the Alternative DEL-1a because the alignment would travel along the north of side of Southwest Genesee Street rather than the south side, it could result in more residential displacements. Another cluster of moderate noise impacts was identified at The Edge Apartment buildings on Southwest Genesee Street between 30th Avenue Southwest and Southwest Avalon Way. These impacts would be caused by the close proximity to the guideway and station along with topographical conditions, which vary greatly, placing some receiver locations with balconies above the light rail tracks, increasing impacts. The last cluster of single- and multi-family residences with predicted moderate noise impacts would be between Southwest Avalon Way and 32nd Avenue Southwest on Southwest Genesee Street. Residences in this cluster would also be elevated and within 500 feet of the station.

The FTA Category 1 land use, the Secret Studio Records/Studio 1208, on the southwest corner of 23rd Avenue Southwest and Southwest Andover Street, is predicted to have a moderate noise impact.

A noise analysis was performed at the frequent use areas in Longfellow Creek Natural Area and no noise impacts were identified.

Under Option DEL-1b, there would be a 625-foot-radius curve just west of Delridge Way between Southwest Dakota Street and Southwest Andover Street followed by another 625-foot-radius curve north of Southwest Genesee Street and west of 26th Avenue Southwest where the track would curve south to go west along Southwest Genesee Street. The last curve for the alternative, with an 1,800-foot radius, would be midway between 28th Avenue Southwest and 30th Avenue Southwest on Southwest Genesee Street.

Option DEL-1b would have only one crossover along Delridge Way Southwest at the intersection with Southwest Andover Street. The crossover would be near single- and multi-family residences and was included in the analysis. The crossover would contribute to noise impacts identified in this area.

Dakota Street Station Lower Height Alternative (DEL-2a)

Alternative DEL-2a could connect to all Build Alternatives in the Duwamish Segment and to Alternative WSJ-3a or Option WSJ-3b in the West Seattle Junction Segment. It would have a lower track alignment than Alternative DEL-1a, to connect to these tunnel alternatives. The lower guideway elevations for the Alternative DEL-2a would have more severe and moderate impacts than alternatives with higher profile guideway elevations.

Severe noise impacts along Delridge Way Southwest would be similar to Alternative DEL-1a on the east side of the alignment, with severe noise impacts at single- and multi-family residences along 23rd Avenue Southwest, south of Andover Street and 26th Avenue Southwest, near the station. Along Southwest Genesee Street, severe noise impacts would occur at most residences adjacent to the guideway between 28th Avenue Southwest and 30th Avenue Southwest due to close proximity to the guideway.

Moderate impacts were identified at single- and multi-family residences between the north end of 22nd Avenue Southwest and Delridge Way Southwest to Southwest Andover Street, due in part to the elevation of the receiver relative to the guideway, at the upper floors of multi-family buildings and the Pigeon Point hillside and the general proximity to the guideway and double crossover at Southwest Andover Street. Added noise from bells at the station would cause moderate noise impacts at those residences near the station. East of the station, moderate impacts were identified at single- and multi-family residences between 25th Avenue Southwest and Delridge Way Southwest at Southwest Genesee Street. To the west of the station, the largest cluster of moderate noise impacts would occur at lower level floors of the Youngstown Flats, in addition to the severe noise impacts, as well as at nearly all single- and multi-family residences along Southwest Adams Street and Southwest Nevada Street near 26th Avenue Southwest, where lower existing noise levels would result in a lower criteria level. Additional moderate noise impacts are also predicted at several single- and multi-family residences along Southwest Nevada Street, west of 28th Avenue Southwest.

Secret Studios Records/Studio 1208, on the southwest corner of 23rd Avenue Southwest and Southwest Andover Street, is predicted to have a moderate noise impact.

A noise analysis was performed at the frequent use areas in Longfellow Creek Natural Area and no noise impacts were identified.

Alternative DEL-2a would only have two curves under 1,250 feet, both with a curve radius of 625 feet found just east of Delridge Way between Southwest Dakota Street and Southwest Andover Street and east as the guideway bends to turn west and travel along Southwest Genesee Street.

Alternative DEL-2a would have one crossover along Delridge Way Southwest at the intersection with Southwest Andover Street. The crossover would be near single- and multi-family residences and was included in the light rail analysis. The crossover would contribute to noise impacts identified in this area.

Dakota Street Station Lower Height North Alignment Option (DEL-2b)

Option DEL-2b could connect to all Build Alternatives in the Duwamish Segment and Alternative WSJ-3a and Alternative WSJ-3b in the West Seattle Junction Segment.

Option DEL-2b would generally share a similar track elevation and route with Alternative DEL-2a, but the guideway would have a slightly higher elevation than the Dakota Street Station Lower Height Alternative (DEL-2a). West of the station, Option DEL-2b would travel north of Southwest Genesee Street, rather than south, and would have a lower elevation for connection to the tunnel near the West Seattle Junction Segment. The higher guideway elevation would result in less severe and moderate noise impacts than Alternative DEL-2a.

With this alternative, severe noise impacts would occur at single- and multi-family residences east of the guideway from 23rd Avenue Southwest at Delridge Way to Southwest Dakota Street. A number of factors would contribute to severe noise impacts in this area, including proximity to the guideway, elevation of receiver relative to the guideway, and proximity to a crossover. Severe noise impacts would also occur at single- and multi-family residences on 26th Avenue Southwest west of the station and at some units in the southeast corner of the Youngstown Flats. Other single- and multi-family residences that would have severe noise impacts are along Southwest Genesee Street between 28th Avenue Southwest and 30th Avenue Southwest.

The moderate noise impact locations would be similar to the moderate impacts under Alternative DEL-2a. There would be less impacts with Option DEL-2b because of the slightly higher guideway elevation, which would increase the structural shielding from the far track at many single- and multi-family units along Delridge Way Southwest, with less impacts along Southwest Genesee and Southwest Nevada streets due to track location and residential displacements.

Secret Studio Records/Studio 1208, on the southwest corner of 23rd Avenue Southwest and Southwest Andover Street, is predicted to have a moderate noise impact.

A noise analysis was performed at the frequent use areas in Longfellow Creek Natural Area and no noise impacts were identified.

Option DEL-2b would have two curves with a curve radius of 625 feet found just west of Delridge Way Southwest between Southwest Dakota Street and Southwest Andover Street and as the guideway bends to turn west and travel along Southwest Genesee Street.

Under this option there would only be one crossover along Delridge Way Southwest at the intersection with Southwest Andover Street. The crossover would be near single- and multi-family residences and was included in the light rail analysis. The crossover would contribute to noise impacts identified in this area.

<u>Delridge Way Station Alternative (DEL-3)</u>

Alternative DEL-3 could connect to all Duwamish Segment Build Alternatives and Alternative WSJ-1, Alternative WSJ-2, or Alternative WSJ-4 in the West Seattle Junction Segment.

The only severe noise impacts were identified at upper-floor units at The Edge Apartments. These buildings would also have the highest number of moderate impacts for this alternative. Another cluster of moderate noise impacts would be found at the Youngstown Flats. While the apartment building would be farther from the guideway than with Alternative DEL-1a, Option DEL-1b, Alternative DEL-2a, and Option DEL-2b, the upper floors of the building would have impacts from this alternative. The double crossover north of the station, as well as the elevation of receiver relative to the guideway elevations on the upper floors of multi-family units and proximity to the guideway, would cause moderate noise impacts for single- and multi-family residences from the north end of 22nd Avenue Southwest to Southwest Andover Street and at residences along 23rd Avenue Southwest, Delridge Way Southwest, and 25th Avenue Southwest south of Southwest Andover Street. Moderate residential noise impacts would extend on both sides of the guideway from Delridge Way Southwest to 30th Avenue Southwest, including some residences in between Southwest Genesee Street and Southwest Nevada Street.

Secret Studio Records/Studio 1208, on the southwest corner of 23rd Avenue Southwest and Southwest Andover Street, is predicted to have a moderate noise impact.

A noise analysis was performed at the frequent use areas in Longfellow Creek Natural Area and no noise impacts were identified.

Alternative DEL-3 would have a 625-foot-radius curve north of Delridge Station on Delridge Way Southwest near the intersection with Southwest Andover Street. South of the Delridge Station, a 750-foot-radius curve would be on Delridge Way Southwest between Southwest Dakota Street and Southwest Genesee Street followed by about 625-foot-radius curve on 25th Avenue just north of Southwest Genesee Street as the guideway would begin to turn west.

Alternative DEL-3 would have one crossover along Delridge Way Southwest just at the intersection with 23rd Avenue Southwest. The crossover would be near single- and multi-family residences and was included in the analysis. The crossover would contribute to noise impacts identified in this area.

<u>Delridge Way Station Lower Height Alternative (DEL-4)</u>

Alternative DEL-4 could connect to all Build Alternatives in the Duwamish Segment and Alternative WSJ-3a and Option WSJ-3b in the West Seattle Junction Segment. It would have a similar alignment as Alternative DEL-3 but would have a lower track elevation, resulting in a slight reduction in moderate impacts but an increase in severe noise impacts.

Three single-family residences between Southwest Dakota Street and Southwest Genesee Street on 25th Avenue Southwest would have a severe noise because of the elevation of the receiver relative to the guideway. Many of the other single- and multi-family residences in the area are predicted to have moderate noise impacts. Other severe noise impacts would occur at first-row single- and multi-family housing on Southwest Genesee Street between 28th Avenue Southwest and 30th Avenue Southwest, while nearly all other residences within this block would have moderate noise impacts due to second and third row acoustical shielding provided by buildings directly in front of them. One single-family residence on the southeast corner of Southwest Nevada Street and 28th Avenue would have a severe noise impact despite being further away from the guideway due to the elevation of the receiver relative to the guideway and lack of shielding.

The largest concentration of moderate noise impacts would occur where the guideway would be lower and the alignment transitions from Delridge Way Southwest to travel west along Southwest Genesee Street, between 23rd Avenue Southwest and 26th Avenue Southwest. Another concentration of moderate noise impacts would occur at the Youngstown Flats. While the apartment building would be further from the guideway, impacts would occur at the upper floors, which are in close proximity to the station. The double crossover north of the station, as well as high receiver elevation and proximity to the guideway, would cause moderate noise impacts for single- and multi-family residences along 22nd Avenue Southwest near Southwest Charleston and south towards Southwest Andover Street. As the guideway would decrease in elevation, it would cause moderate noise impacts for residences from 26th Avenue Southwest to 30th Avenue Southwest. West of 30th Avenue Southwest, moderate impacts are predicted for The Edge Apartments, which would be in close proximity to the guideway.

Secret Studio Records/Studio 1208, on the southwest corner of 23rd Avenue Southwest and Southwest Andover Street, is predicted to have a moderate noise impact.

A noise analysis was performed at the frequent use areas in Longfellow Creek Natural Area and no noise impacts were identified.

Alternative DEL-4 would have a 625-foot-radius curve north of Delridge Station on Delridge Way Southwest near the intersection with Southwest Andover Street. South of Delridge Station, a 750-foot-radius curve would be on Delridge Way Southwest between Southwest Dakota Street and Southwest Genesee Street followed by about 625-foot-radius curve on 25th Avenue Southwest, just north of Southwest Genesee Street as the guideway would begin to turn west.

There would be one crossover in Alternative DEL-4 along Delridge Way Southwest at the intersection with 23rd Avenue Southwest. The crossover would be near single- and multi-family residences and was included in the light rail analysis. The crossover would contribute to noise impacts identified in this area.

Andover Street Station Alternative (DEL-5)

Alternative DEL-5 could connect to all Build Alternatives in the Duwamish Segment and Alternative WSJ-1, Alternative WSJ-2, and Alternative WSJ-4 in the West Seattle Junction Segment. This alternative would travel west of Delridge Way Southwest and head south until turning west along Southwest Andover Street. It then would turn south on Southwest Avalon Way. This alternative would have the most overall noise impacts and most severe noise impacts compared to the other Delridge Segment alternatives because of the close proximity of the guideway to several large multi-family units along Southwest Avalon Way.

All of the severe noise impacts would be at single- and multi-family apartments and condominiums along 32nd Avenue Southwest and Southwest Avalon Way between Southwest Andover Street and Southwest Genesee Street. Not only would many of the buildings be close to the guideway, but many severe impacts at multi-family residences would occur at upper-floor units overlooking the guideway.

Residences predicted to have moderate impacts include the north-facing units of the Youngstown Flats and the nearby single-family residences on 26th Avenue Southwest. While the structures would be more than 300 feet away from the guideway, the area itself has lower noise levels than other surrounding areas and there is little, if any, acoustical shielding. Moderate noise impacts would occur for first-row residences along Southwest Yancy Street between 28th Avenue Southwest and 30th Avenue Southwest, including housing for Transitional Resources, as well as single- and multi-family residences on the east corners of Southwest Dakota Street and Southwest Adams Street at 30th Avenue Southwest.

West of the guideway along Southwest Avalon Way, moderate noise impacts were identified at most first-row housing with no acoustical shielding between Southwest Yancy Street and Southwest Genesee Street. Another cluster of moderate noise impacts was identified at several multi-story apartment buildings on Southwest Genesee Street and between Southwest Avalon Way and 30th Avenue Southwest as well as single- and multi-family homes along 32nd Avenue Southwest. Many of the buildings that would have moderate noise impacts have limited to no acoustical shielding, and would just meet the moderate noise level criteria, at 1 to 2 dB over the criteria level. First-row single- and multi-family residences on Southwest Avalon Way are also predicted to have moderate noise impacts. Residences in this area would have lower local noise levels and also just meet the moderate noise level criteria.

A noise analysis was performed at the frequent use areas in Longfellow Creek Natural Area and no noise impacts were identified.

Alternative DEL-5 would have three curves with a radius under 1,250 feet. The first, with a 625-foot radius, would be just slightly west of the intersection with Delridge Way Southwest and Southwest Andover Street. As the guideway would begin to turn south before traveling along Southwest Avalon Way, a 1,000-foot-radius curve would be on Southwest Yancy Street at the intersection with 28th Avenue Southwest and Southwest Avalon Way. The final curve of 625 feet would be west of Southwest Avalon Way near the intersection with Southwest Genesee Street where the track would begin to curve east again before Avalon Station in the West Seattle Junction Segment.

<u>Andover Street Station Lower Height Alternative (DEL-6a)</u>

Alternative DEL-6a could connect to all Build Alternatives in the Duwamish Segment and Preferred Option WSJ-5b and Alternative WSJ-5a in the West Seattle Junction Segment. This alternative would travel southwest of Delridge Way Southwest and then travel west across Southwest Andover Street before turning south again along the east side of the West Seattle Bridge as it transitions to Fauntleroy Way Southwest. This alternative would have the fewest overall noise impacts and the fewest moderate noise impacts.

All of the severe noise impacts would occur at a single-family residences on 32nd Avenue Southwest between Southwest Andover Street and Southwest Genesee Street, where residences would have minimal to no acoustical shielding and would be in close proximity to the guideway.

The largest concentration of moderate impacts would occur at the upper-level units of the City Views Apartments on Southwest Bradford Street west of Southwest Avalon Way and north of Southwest Andover Street. Additional moderate impacts would occur at the Youngstown Flats and a single-family residence across from the apartment building on 26th Avenue Southwest. First-row housing along 32nd Avenue Southwest between Southwest Yancy Street and Southwest Genesee Street are also predicted to have moderate noise impacts.

A noise analysis was performed at the frequent use areas in Longfellow Creek Natural Area, and no noise impacts were identified.

Three curves were identified for Alternative DEL-6a. The first, a 625-foot-radius curve, would be just southwest of Delridge Station and north of Southwest Andover Street slightly east of the intersection with Charlestown Street. A 950-foot-radius curve would be near Southwest Yancy Street at the north end of 32nd Avenue Southwest. The last curve, with a 675-foot radius, would be at the Delridge-West Seattle Junction border east of West Seattle Bridge. There are no crossovers within the Delridge Segment under Alternative DEL-6a.

Andover Street Station Lower Height No Avalon Station Tunnel Connection (DEL-7)

Alternative DEL-7 could connect to all Build Alternatives in the Duwamish Segment and Alternative WSJ-6 in the West Seattle Junction Segment. This alternative would travel southwest of Delridge Way Southwest and then west near Southwest Yancy Street before turning slightly southwest and transitioning to a tunnel just before the West Seattle Bridge.

All of the severe noise impacts would occur at the west end of the alignment, with a large cluster of impacts at the Transitional Resources residences along Southwest Yancy Street as well at several single-family houses where residences are in close proximity to the guideway. Other severe impacts would occur at residences along 32nd Avenue Southwest, Andover Way Southwest, and Southwest Avalon Way, including the Transitional Resources building on Southwest Avalon Way and an apartment building on the southwest corner of Southwest Avalon Way and Southwest Andover Street.

The largest concentration of moderate noise impacts would occur at the Youngstown Flats, along with single-family residences adjacent to the apartment building. Other moderate impacts would occur at single- and multi-family households along Southwest Yancy Street and upper-floor units on Southwest Dakota Street between 28th Avenue Southwest and 30th Avenue Southwest, single-family residences along Southwest 32nd Avenue, single- and multi-family residences on Southwest Avalon Way, and the upper-floor units of the City View Apartments.

A noise analysis was performed at the frequent use areas in Longfellow Creek Natural Area and no moderate noise impact would occur from light rail operations.

Alternative DEL-7 would have a 625-foot-radius curve north of Delridge Station on Delridge Way Southwest near the intersection with Southwest Charlestown Street. There are two additional curves south of Delridge Station, a 675-foot-radius curve along the east side of the guideway and 625-foot-radius curve along the west side of the guideway near the intersection of Southwest Andover Street and 26th Avenue Southwest.

There would be no crossovers within the Delridge Segment under Alternative DEL-7.

Delridge Segment Bus Operations

Bus operations were reviewed for potential noise impacts. Bus operations under Alternatives DEL-1a, DEL-1b, DEL-2a, DEL-2b, DEL-3, DEL-4, DEL-5, and DEL-6a would occur on existing roadways, including Delridge Way Southwest, Southwest Andover Street, 25th Avenue Southwest and 26th Avenue Southwest, and no analysis was required. For Preferred Option DEL-6b and Alternative DEL-7, southbound buses would connect to the Delridge Station through a commercial area near Southwest Charlestown Street, with no noise sensitive land uses; therefore, no impacts were identified.

West Seattle Junction Segment

Noise impacts for the West Seattle Junction Segment are shown in Table 6-3 and on Figure 6-3. Alternative WSJ-3a, Option WSJ-3b, and Alternative WSJ-6 would be entirely in tunnels and would not have any airborne noise impacts; therefore, they are not discussed further in this section. Preferred Option WSJ-5b and Alternative WSJ-5a would have the fewest number of airborne noise impacts in the West Seattle Junction Segment. Alternative WSJ-1, Alternative WSJ-2, and Alternative WSJ-4 assume a connection to Alternative DEL-1a in the Delridge Segment. Connections to other Delridge Segment alternatives could result in some moderate impacts changing to severe impacts, but the overall number of impacts would be similar. Detailed figures displaying the locations of noise impacts and tables with detailed noise analysis information are provided in Attachments N.3D and N.3F.

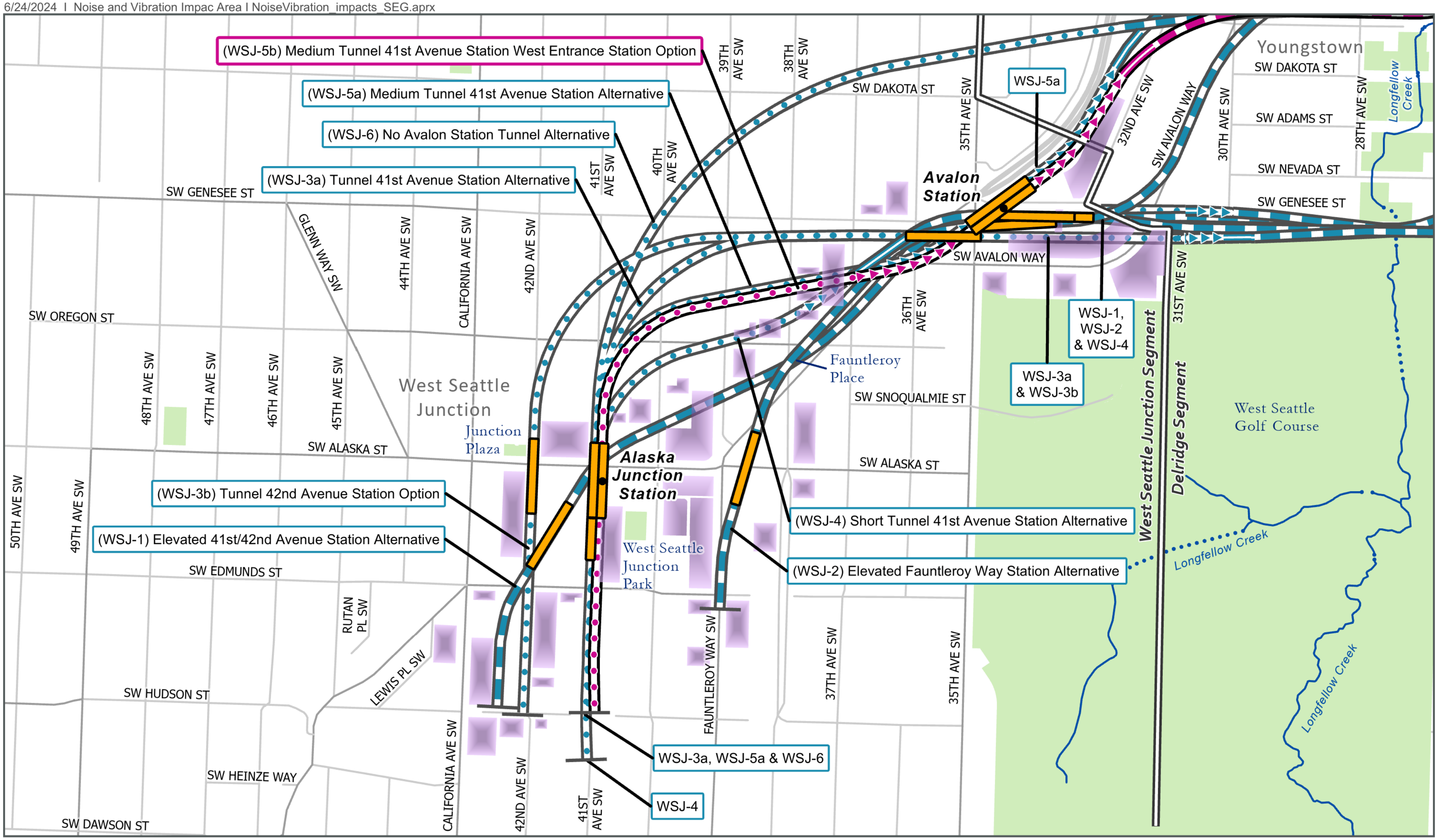
Table 6-3. Summary of Light Rail Noise Impacts by Alternative for the West Seattle Junction Segment

Alternatives and Design Options	Category 1 Noise Impacts	Category 2 Moderate Noise Impacts	Category 2 Severe Noise Impacts	Category 3 Noise Impacts	Total Noise Impacts
Preferred Medium Tunnel 41st Avenue Station West Entrance Station Option (WSJ-5b)	**0**	**5**	**0**	**0**	**5**
Elevated 41st/42nd Avenue Station Alternative (WSJ-1)	0	359	54	1	414
Elevated Fauntleroy Way Station Alternative (WSJ-2)	0	275 to 332	15 to 81	0	312 to 356
Tunnel 41st Avenue Station Alternative (WSJ-3a)	0	0	0	0	0
Tunnel 42nd Avenue Station Option (WSJ-3b)	0	0	0	0	0
Short Tunnel 41st Avenue Station Alternative (WSJ-4)	0	140	0	0	140
Medium Tunnel 41st Avenue Station Alternative (WSJ-5a)	0	5	0	0	5
No Avalon Station Tunnel Alternative (WSJ-6)	0	0	0	0	0

Note: The numbers presented are the number of units, counted by individual residences, including individual units of multi-family structures, and number of structures for other uses, like schools, churches, and parks. Category 2 parcels are evaluated with the 24-hour Ldn and Category 1 and 3 are evaluated with the peak hour Leq.

The West Seattle Junction Segment includes the area generally west of 31st Avenue Southwest between Southwest Charlestown Street and Southwest Hudson Street. A noise impact analysis was performed for Preferred Option WSJ-5b, Alternative WSJ-1, Alternative WSJ-2, Alternative WSJ-4, and Alternative WSJ-5a. All other West Seattle Junction Segment alternatives are entirely within tunnels in this segment and therefore would not result in noise impacts from light rail operation.

Of the analyzed alternatives, Preferred Option WSJ-5b and Alternative WSJ-5a would have the least overall noise impacts and no severe noise impacts, and Alternative WSJ-1 and Alternative WSJ-2 would have the most overall noise impacts. Each alternative would have two stations, Avalon Station and Alaska Junction Station, with the exception of Alternative WSJ-6. However, Preferred Option WSJ-5b, Alternative WSJ-4, and Alternative WSJ-5a would enter into a tunnel before the Alaska Junction Station and therefore would have a lower guideway elevation than the other two elevated alternatives. Alternative WSJ-1 would be aligned west of Fauntleroy Way Southwest, between 41st Avenue Southwest and 42nd Avenue Southwest, while Alternative WSJ-2 would be along Fauntleroy Way Southwest.



Source: City of Seattle, King County (2023).

Preferred Alternative
- Elevated
- Tunnel
- At-Grade
- Retained Cut

Other Alternatives
- Elevated
- Tunnel
- At-Grade
- Retained Cut

Station (● *Indicates Preferred Alternative*)
- New

- Segment Line
- Stream
- Piped Stream
- Park
- Area of Noise Impact

0 500 1,000 Feet N

FIGURE 6-3
Noise Impacts (before mitigation)
West Seattle Junction Segment

West Seattle Link Extension

Preferred Medium Tunnel 41st Avenue Station West Entrance Station Option (WSJ-5b)

Preferred Option WSJ-5b could connect to Preferred Option DEL-6b and Alternative DEL-6a in the Delridge Segment. Beginning in the Delridge Segment, Preferred Option WSJ-5b begins in a retained cut south of Southwest Yancy Street and follows the east side of the West Seattle Bridge connection to Southwest Genesee Street in the West Seattle Junction Segment. The alignment enters a tunnel north of Fauntleroy Way Southwest at 37th Avenue Southwest. This alternative would have the least overall noise impacts for the above-grade alternatives and no severe noise impacts.

Moderate noise impacts are predicted along 32nd Avenue Southwest just north of the intersection with Southwest Genesee Street. The single-family residences would have moderate noise impacts due to the close proximity to the guideway and little to no acoustical shielding.

Preferred Option WSJ-5b would have a 675-foot-radius curve at the Delridge Segment/West Seattle Junction Segment boundary east of West Seattle Bridge/Fauntleroy Way Southwest. There are no Category 1 Land Uses in the West Seattle Junction Segment. There are no noise-sensitive parks in the West Seattle Junction Segment.

Elevated 41st/42nd Avenue Station Alternative (WSJ-1)

Alternative WSJ-1 could connect to Alternative DEL-1a, Option DEL-1b, Alternative DEL-3, and Alternative DEL-5 in the Delridge Segment. The alternative would travel along the south side of Southwest Genesee Street between 31st Avenue Southwest and Fauntleroy Way Southwest. The alternative would transition to the west side of Fauntleroy Way Southwest. The guideway would turn south in the vicinity of 41st Avenue Southwest and Southwest Alaska Street and continue south to Southwest Hudson Street terminating with a tail track on the west side of 42nd Avenue Southwest. It is the longest West Seattle Junction Segment alternative that was analyzed.

Alternative WSJ-1 would have the most noise impacts of all the West Seattle Junction Segment Build Alternatives.

One Category 3 noise impact would occur at a church on the northwest corner of 39th Avenue Southwest and Southwest Oregon Street, due to close proximity to the guideway. Several single- and multi-family residences on 40th Avenue Southwest would have severe noise impacts due to proximity to the guideway and lack of structural shielding. They would also be in direct line of sight of the double crossover north of Alaska Junction Station. Severe noise impacts would occur at a multi-story mixed-use apartment building on the northwest corner of Southwest Alaska Street and 41st Avenue Southwest. The impacted apartments would be less than 50 feet from the guideway, within 500 feet of Alaska Junction Station and overlook the guideway. The remaining apartments would face the guideway, but would be farther away, and would have moderate noise impacts. Other severe noise impacts would include multi-story apartments on the west side of 42nd Avenue Southwest within 50 feet of Alaska Junction Station; the remaining apartments would have moderate noise impacts. South of Avalon Station, single- and multi-family residences on California Avenue Southwest would all have both moderate and severe noise impacts, with the closest building to the guideway having a severe impact for the top floor. At the end of the alignment, a multi-story apartment building on the southeast corner of California Avenue Southwest and Southwest Hudson Street would have several severe impacts for the uppermost floors due to high receiver elevation and close proximity (20 feet) to the guideway; the remaining residences for the north half of the block would have moderate noise impacts.

The largest cluster of moderate noise impacts includes most of the multi-story apartments and condominiums on the north side of Southwest Avalon Way between Southwest Genesee Street and 35th Avenue Southwest. This block of housing would be adjacent to Avalon Station. Buildings closest to the guideway would have severe impacts at the uppermost floors. Other floors and buildings would have moderate noise impacts. There would also be moderate noise impacts at several single-family residences along 32nd Avenue Southwest north of Southwest Genesee Street.

Additional moderate noise impacts would occur at several multi-family units on 42nd Avenue Southwest, 41st Avenue Southwest, and 40th Avenue Southwest. The affected units would all be within 500 feet of the Alaska Junction Station. Moderate noise impacts are also predicted at a multi-story building within 500 feet of Alaska Junction Station at the north corner of California Avenue Southwest and Erskine Way Southwest, a multi-story apartment building with 300 feet of the double crossover on 40th Avenue Southwest, and several multi-family units, which have minimal or no acoustical shielding from noise at Alaska Station.

The residences along the northwest corner of Fauntleroy Way Southwest and 37th Avenue north of the alignment would have moderate impacts primarily because of guideway proximity and no acoustical shielding. The single- and multi-family residences along 40th Avenue Southwest that would also have moderate noise impacts are affected by proximity to the guideway and being within 300 feet of the double crossover with minimal to no shielding.

Following Sound Transit policy and the discussion in Section 4.1.1.5, the West Seattle Junction Segment was reviewed for curves with the potential for wheel squeal. Alternative WSJ-1 has three curves with the potential for wheel squeal. All of the curves would have a 625-foot radius. These curves would be on Fauntleroy Way Southwest between Southwest Avalon Way and 35th Avenue Southwest as the guideway turns southwest along Fauntleroy Way Southwest, at the intersection of Southwest Alaska Street and 41st Avenue Southwest before Alaska Junction Station, and just west of intersection of Southwest Edmunds Street and 42nd Avenue Southwest after Alaska Junction Station.

Alternative WSJ-1 would have one crossover on the elevated trackway near 40th Avenue Southwest between Southwest Oregon Street and Southwest Alaska Street. The crossover would contribute to noise impacts in this area.

<u>Elevated Fauntleroy Way Station Alternative (WSJ-2)</u>

Alternative WSJ-2 could connect to Alternative DEL-1a, Option DEL-1b, Alternative DEL-3, and Alternative DEL-5. This alternative would travel along the south side of Southwest Genesee Street between 31st Avenue Southwest and Fauntleroy Way Southwest. It would then head southwest on Fauntleroy Way Southwest and continue along the west side of Fauntleroy Way Southwest. The guideway would cross to the east side of Fauntleroy Way Southwest south of Southwest Oregon Street. The alternative would terminate with tail tracks within the Fauntleroy Way Southwest right-of-way just past Southwest Edmunds Street.

Alternative WSJ-2, when connecting to Alternative DEL-5 in the Delridge Segment, would have the most severe noise impacts of all the West Seattle Junction Segment alternatives.

The largest concentration of severe noise impacts would be at Fauntleroy Way Southwest near the end of the alignment at a four-story apartment building. One other severe noise impact would occur at a single-family residence at the intersection of Southwest Oregon Street and 38th Avenue Southwest, where the structure would be in close proximity to the guideway, have no acoustical shielding from the guideway, and would be within 300 feet of a double crossover just north of Alaska Junction Station.

When connecting to Alternative DEL-5, some moderate noise impacts would change to severe noise impacts at multi-story apartment buildings on Southwest Avalon Way between Southwest Genesee Street and 35th Avenue Southwest. It would also have more severe impacts when connecting to Alternative DEL-5 than it would connecting to Alternative DEL-1a.

Moderate noise impacts for this alternative would occur at single- and multi-family residences starting from the southwest corner of Southwest Genesee Street and Southwest Avalon Way and continue to 35th Avenue Southwest, affecting residences north and south of the guideway. Affected residences would be in close proximity to the guideway, have no acoustical shielding, or a combination of both. All residences with moderate noise impacts would be within 500 feet of Avalon Station. The largest concentration of moderate noise impacts is predicted for several multi-story apartment complexes south of Avalon Station.

At 36th Avenue Southwest and Southwest Genesee Street a small cluster of single- and multi-family residences would have moderate noise impacts due to close guideway proximity, no acoustical shielding, and being within 500 feet of Avalon Station. The double crossover between Avalon Station and Alaska Junction Station would be primarily responsible for the moderate noise impacts on 37th Avenue Southwest.

Another concentration of identified moderate noise impacts would be at two apartment buildings to the west of Alaska Junction Station on the corners of Southwest Alaska Street and Fauntleroy Way Southwest. Both buildings would have high receiver elevations and their uppermost floors would overlook or be at level with Alaska Junction Station. They also would be in close proximity to the guideway and would not have any acoustical shielding. To the east of Alaska Junction Station, all the mixed-use, multi-story residences on 38th Avenue Southwest between Fauntleroy Way Southwest and Southwest Alaska Street would have moderate noise impacts. These buildings would be near the guideway and have no acoustical shielding due in part to the high receiver elevations. The buildings would be within 500 feet of Alaska Junction Station or 300 feet of the double crossover and in some cases, both. The last cluster of moderate noise impacts would occur on both the east and west sides of Fauntleroy Way Southwest south of Southwest Edmunds Street.

With Alternative WSJ-2, two 625-foot-radius curves would be between Avalon Station and Alaska Junction Station. The first would be at the intersection of 36th Avenue Southwest and Fauntleroy Way Southwest where the guideway turns southwest and the second curve at the intersection of Fauntleroy Way Southwest and 38th Avenue Southwest as the guideway angles closer to south. A remaining curve, with a 750-foot radius, would be at Fauntleroy Way Southwest between Southwest Alaska Street and Southwest Edmunds Street after Alaska Junction Station and before the end of the light rail line.

There would be only one crossover within this alternative, on the elevated trackway along Fauntleroy Way Southwest at the intersection with Southwest Oregon Street. The crossover would contribute to noise impacts in this area.

Short Tunnel 41st Avenue Station Alternative (WSJ-4)

Alternative WSJ-4 could connect to Alternative DEL-1a, Option DEL-1b, Alternative DEL-3, or Alternative DEL-5. The alternative would travel along the south side of Southwest Genesee Street from 31st Avenue Southwest to the west side of Fauntleroy Way Southwest. It would continue along the west side of Fauntleroy Way Southwest on elevated guideway before transitioning to at-grade near 37th Avenue Southwest. It would then turn west near Southwest Oregon Street and transition into a tunnel with a portal in the vicinity of Southwest Oregon Street and 38th Avenue Southwest. The alternative would have fewer moderate noise impacts than Alternative WSJ-1 or Alternative WSJ-2 and no severe noise impacts.

The majority of moderate noise impacts would occur at residences near Avalon Station and would primarily affect multi-family residences along Southwest Avalon Way between 35th Avenue Southwest and Southwest Genesee Street. Other single- and multi-family residences that would have moderate impacts are around the intersection of Southwest Genesee Street and 32nd Avenue Southwest. West of Avalon Station, multi-family residences on the north side of Southwest Genesee Street between 36th Avenue Southwest and 37th Avenue Southwest would have moderate noise impacts because of their proximity to the guideway and no acoustical shielding.

Alternative WSJ-4 would only have two curves at a 1,250-foot radius or less. The first would be a 625-foot-radius curve at the intersection of Fauntleroy Way and Southwest Genesee Street after Avalon Station where the track turns southwest. The final curve would be within the cut-and-cover portion of the guideway just before entering the tunnel portal and therefore would not have an impact on surrounding residences.

Medium Tunnel 41st Avenue Station Alternative (WSJ-5a)

Alternative WSJ-5a would connect to Preferred Option DEL-6b and Alternative DEL-6a. Beginning in the Delridge Segment, the alternative begins in a retained cut south of Southwest Yancy Street and follows the east side of the West Seattle Bridge connection to Southwest Genesee Street in the West Seattle Junction Segment. The alignment enters a tunnel at Southwest Genesee Street and 37th Avenue Southwest. This alternative would have the least overall noise impacts for the above-grade alternatives and no severe noise impacts.

Moderate noise impacts are predicted along 32nd Avenue Southwest just north of the intersection with Southwest Genesee Street and at one residence on the south side of Southwest Genesee Street. The single-family residences would have moderate noise impacts due to the close proximity to the guideway and little to no acoustical shielding.

Alternative WSJ-5a would have a 675-foot-radius curve that would be shared with Alternative DEL-6a. It would be at the Delridge Segment/West Seattle Junction Segment boundary east of West Seattle Bridge/Fauntleroy Way. There are no Category 1 Land Uses in the West Seattle Junction Segment. There are no noise-sensitive parks in the West Seattle Junction Segment.

West Seattle Junction Segment Bus Operations

All buses serving the station alternatives in the West Seattle Junction Segment would be along existing roadways, including Southwest Avalon Way, 35th Avenue Southwest, Southwest Alaska Street, and Fauntleroy Way Southwest; therefore, no noise analysis for buses was required.

6.1.2 Traffic Noise Impact Analysis

This section provides an analysis of project-related areas considered for traffic noise impacts in the West Seattle Link Extension area. There are potential traffic revisions planned as part of the West Seattle Link Extension along with some removal of shielding that could result in increased traffic noise levels. As required by the FTA, if the transit project could result in traffic noise impacts, then the project must also evaluate the traffic noise and identify impacts and provide mitigation consistent with agency policy. In most locations, the slight modifications to traffic or removal of shielding are not predicted to cause a measurable change in traffic noise levels and no traffic noise analysis is required. Locations where increased traffic noise levels could cause new project-related traffic noise impacts are evaluated in the following sections.

6.1.2.1 No Build Alternative

Under the No Build Alternative, traffic noise levels would continue to be dominated by major and minor arterial roadways including traffic on the West Seattle Bridge. Other major roadways with high levels of traffic noise include 4th Avenue South and Alaskan Way in the SODO and Duwamish segments. Roadways with major contributions to noise in the Delridge Segment area include Delridge Way Southwest, Southwest Genesee Street, Southwest Avalon Way, Fauntleroy Way Southwest, and 35th Avenue Southwest. Major roadways in the West Seattle Junction Segment area include Fauntleroy Way Southwest and 35th Avenue Southwest in addition to Southwest Alaska Street, and California Avenue Southwest. These roadways would continue to be major noise sources in these areas.

6.1.2.2 Build Alternatives

Although there are some displacements and roadway modifications planned for the West Seattle Link Extension, most are not predicted to result in any new traffic noise impacts.

Within the Delridge Segment, under Preferred Option DEL-6b, Alternative DEL-7, and Alternative DEL-6a, several residences along the east side of 32nd Avenue Southwest could be exposed to noise from the West Seattle Bridge roadway due to the removal of existing residential structures on the west side of 32nd Avenue Southwest. A preliminary traffic noise analysis was performed for the residences that would lose acoustical shielding from Fauntleroy Way Southwest/West Seattle Bridge traffic noise. Based on the preliminary analysis, although noise levels would be expected to increase by 3 to 6 dB over existing conditions, due to the distance from the highway to the residences of over 240 feet, noise levels would remain well below the Federal Highway Administration impact criteria, and therefore no noise impacts were identified.

No other traffic noise related issues were identified for the West Seattle Link Extension.

6.2 Construction Noise Impacts

Construction noise was analyzed using the methodology established in the FTA Guidance Manual (2018) to document predicted noise impacts from the project’s construction. This analysis was conducted for a variety of different construction activities that are anticipated to generate the highest sound levels, require nighttime construction, or are expected to require several months to complete.

An assessment of construction noise levels was performed with noise metrics that can be compared with the City of Seattle construction noise ordinance. The Seattle Municipal Code Chapter 25.08 was used for the criteria for construction noise level limits, along with noise allowances from the Seattle Noise Ordinance for construction activities.

The following activities are expected to produce the highest sound levels, would be done during nighttime hours, or require several months to complete:

- Elevated Light Rail Construction
- Retained-cut Construction
- Tunneling
- Cut-and-cover Station Construction
- Bridge Construction Over Water Crossings

Table 6-4 lists the types of construction equipment used in the analysis with representative sound levels established in the FTA Guidance Manual (2018), which are Leq sound levels 50 feet from the equipment. Construction sound levels were generally predicted using the methodology detailed in Section 7 of the FTA Guidance Manual (2018), which analyzes the two loudest pieces of equipment expected for a particular activity.

Computer noise models were used to predict sound levels at Category 1 land uses from nearby construction activities. The noise models accounted for the effects of distance, topography, and surface reflections on sound levels and used the reference sound levels provided in the FTA Guidance Manual (2018).

Table 6-4. Construction Equipment Sound Levels

Construction Equipment	Sound Level at 50 feet Leq (in dBA)
Air Compressor	80
Backhoe	80
Concrete Mixer	85
Concrete Pump	82
Crane	83
Excavator	81
Generator	82
Impact Pile Driver	101
Jackhammer	88
Loader	80
Pneumatic Tools	85
Roller	85
Truck	84

Source: FTA 2018.

Predicted sound levels from elevated light rail construction, retained-cut construction, tunneling, cut-and-cover station construction, and bridge construction over water crossings are listed in Table 6-5.

Table 6-5. Predicted Construction Sound Levels

Construction Activity	Construction Equipment	Sound Level at 50 feet Leq (dBA) [a]
Elevated Light Rail Construction	Cranes, excavators, concrete pumps, pneumatic tools	85 to 87
Retained-Cut Construction	Cranes, backhoes, jackhammers, excavators, pneumatic tools, concrete mixers	84 to 89
At-Grade Construction	Excavators, backhoes, concrete mixers, concrete pumps, haul trucks, loaders	86 to 87
Ground Improvements	Generators, air compressors, loaders, haul trucks, concrete mixers	80 to 87
Tunneling	Excavators, backhoes, haul trucks, loaders	84 to 86
Cut-and-Cover Station Construction	Excavators, backhoes, haul trucks, loaders, vibratory rollers	84 to 88
Bridge Construction Over Water Crossings	Cranes, pile drivers, concrete mixer, concrete pumps	87 to 101

Source: FTA 2018.

[a] The sound levels show the two loudest pieces of equipment operating at the same time.

6.2.1 Construction Noise Sources

6.2.1.1 Elevated Light Rail Construction

Alternatives that include construction of elevated light rail structures occur in the Duwamish, Delridge, and West Seattle Junction segments.

Demolition of existing structures and relocation of utilities would likely be required in several of these work areas before beginning heavy civil construction. Once heavy civil construction begins, construction activities may include the following:

- Footings and Drilled Shafts – Elevated guideway construction would likely begin with preparation work to construct foundations that may consist of shallow spread footings or drilled shafts. Excavators, cranes, haul trucks, concrete mixers, and concrete pump trucks would likely be used during this work.
- Concrete Guideway Columns and Piers – Following the foundations, concrete guideway columns and piers that support the guideway could be constructed. Equipment anticipated to be used during this work could include cranes, haul trucks, concrete mixers, and concrete pump trucks.
- Elevated Guideway and Falsework – The elevated guideway superstructure could be constructed of either cast-in-place or pre-cast reinforced concrete. Falsework would be required where cast-in-place construction is used to support the superstructure while the concrete is poured and cures. Loud equipment anticipated to be used could include cranes, air compressors, pneumatic tools, haul trucks, concrete mixers, and concrete pump trucks.
- Elevated Station Construction – Construction of the elevated stations would be similar to construction of the guideway but include construction of station platforms and include the use of the same general equipment used for the guideway construction, along with trucks for delivery of materials for station construction and finishing.

The loudest sources of noise would be from cranes and pneumatic tools. Sounds levels from elevated light rail construction may exceed 87 dBA at 50 feet from construction activities.

6.2.1.2 Retained-cut Construction

Alternatives with areas requiring retained-cut construction include the Duwamish, Delridge, and West Seattle Junction segments. Construction activities may include the following:

- Demolition of Existing Structures – Retained-cut construction may involve demolition of existing structures and clearing and grading. Existing structures would need to be removed before excavation. Demolition may include the use of cranes, backhoes, excavators, loaders, haul trucks, and jackhammers.
- Excavation – After any existing structures are removed, excavation activities could begin. Equipment used during excavation may include excavators, loaders, haul trucks, and backhoes.
- Construction of Guideways – Excavation may be necessary to construct the subgrade, track slabs, drainage structures, and below-grade light rail infrastructure. The work may include the use of cranes, air compressors, pneumatic tools, concrete mixers, and concrete pump trucks.
- Construction of Retaining Walls – In some locations, subsurface anchors, or tiebacks may be required to support the retaining walls. Dewatering may also be necessary in some locations. Retaining wall construction could include the use of cranes, haul trucks, concrete mixers, and concrete pump trucks.

The loudest sources of construction noise would be from jackhammers and other demolition equipment, as well as concrete mixers, cranes, and pneumatic tools. Sound levels from retained-cut construction could be over 89 dBA at 50 feet from construction activities.

6.2.1.3 At-Grade Construction

At-grade construction is anticipated to occur primarily within the SODO Segment. Preferred Option SODO-1c, Alternative SODO-1a, and Option SODO-1b include construction of the at-grade SODO Station. Construction activities may include the following:

- Shallow Excavations – Construction of at-grade guideways would be similar to typical road construction and would involve shallow excavations to construct the subgrade, track, and station platform slabs. Equipment used during this process may include haul trucks, loaders, excavators, and backhoes.
- Concrete Pours – After excavation concrete would be poured to form the station platform slabs and may include concrete mixers, and concrete pumps.

The loudest noise sources would be concrete mixers and haul trucks. Sound levels from at-grade construction could be over 87 dBA at 50 feet from construction activities.

6.2.1.4 Ground Improvements

Ground improvements may be needed to address weak soils in order to build on them and may be needed throughout the project corridor. Ground improvements may be necessary in the Duwamish and SODO segments, which are predominantly fill material on top of tide flats.

Ground improvements may include jet grouting, ground freezing, rock displacement, or a combination of these methods. Construction equipment may include generators, air compressors, loaders, haul trucks, and concrete mixers. Construction noise from ground improvements could be over 87 dBA at 50 feet from the construction activities. The loudest sound sources would be concrete mixers and haul trucks.

6.2.1.5 Tunneling

Alternatives with areas requiring mined tunnel construction would include the Delridge and West Seattle Junction segments. Although tunneling may occur under several noise-sensitive properties throughout the project corridor, above-grade construction, which would be concentrated near the tunnel portals and underground station locations are the primary locations for potential construction noise impacts. Construction activities near the tunnel portals may include the following:

- Portal and Shaft Excavation – Tunnel construction requires tunnel portals at the beginning and end of each tunnel for launch and retrieval of equipment. On hillsides, portals may be dug directly into the hillside, while in flatter areas, an access shaft or pit would be excavated from the surface. Soil stabilization would be necessary to support excavation of access shafts or pits. At several locations these pits would also serve as below-grade stations after tunneling has been completed. Construction of portals or shafts would likely require the use of excavators, haul trucks, and backhoes.
- Transporting Spoils – Once tunneling is underway, spoils would be transported back to the tunnel portals and hauled off the site. Spoils would likely be loaded into trucks, or depending on the portal location, by barge or train for removal from the site. Transporting spoils would likely require material conveyors, haul trucks, and loaders. Ventilation fans would also run continuously to supply fresh air to construction crews working inside the tunnel.

The loudest construction sound sources would be excavators, haul trucks and ventilation fans to provide fresh air inside the tunnel. Sound levels near the tunnel portals may be over 86 dBA at 50 feet from construction activities.

6.2.1.6 Cut-and-Cover Construction

Cut-and-cover construction would be used for below-grade station construction for the Alaska Junction Station and tail track in the West Seattle Junction Segment. Construction activities during cut-and-cover work may include the following:

- Excavation – Cut-and-cover construction involves excavating from the surface, similar to retained-cut construction. Excavation may include the use of excavators, haul trucks, and backhoes.
- Transporting Spoils – As excavation is underway the excavated materials would likely need to be removed from the site. Removal of excavated materials would likely require the use of haul trucks, and loaders.
- Backfill – Cut-and-cover construction also requires backfilling with imported fill or suitable excavated material after construction of the lid or station roof. This may require the use of excavators, backhoes, haul trucks, and vibratory rollers.
- Roadway Repair – Roadways that are removed and replaced as part of the project may need to be reconstructed. Roadway repairs may occur throughout the project area. Equipment would include pavers, backhoes, haul trucks, and vibratory rollers.

The loudest sources of noise would include haul trucks and vibratory rollers. Sound levels may be over 88 dBA at 50 feet from construction activities.

6.2.1.7 Bridge Construction over the Duwamish Waterway

Alternatives in the Duwamish Segment may include the following construction activities for crossing the Duwamish Waterway:

- Construct Temporary Work Trestles, Piles and Install Cofferdams – Temporary work trestles may need to be constructed to support material deliveries and operation of heavy equipment. Construction of temporary work trestles would be accomplished by driving or vibrating steel-pipe piles into the ground and constructing bents, framing, and decking. Temporary piles and sheet piles for cofferdam walls would be driven or vibrated into place, and the bridge support columns would be installed within the dewatered cofferdams. Temporary work trestle and cofferdam construction may require impact and/or vibratory pile drivers, delivery trucks, and cranes.
- Construct Bridge Segments – Bridge superstructures would follow construction of the bridge foundations. Cranes, concrete pump trucks, and mixers would likely be used during construction of the bridge segments.

The loudest type of construction equipment would be pile drivers. During pile installation sound levels may exceed 101 dBA at 50 feet from pile-driving. Other construction activities would likely be 87 dBA at 50 feet.

6.2.2 No Build Alternative

Under the No Build Alternative, construction would not take place and no impacts from construction noise would occur.

6.2.3 Build Alternatives

Residential neighborhoods are near the west end of the Duwamish Segment and throughout the Delridge Segment and the West Seattle Junction Segment. Noise impacts from construction activities are most likely to occur at residential properties within these segments. The SODO and Duwamish segments are mostly comprised of industrial and commercial properties.

6.2.3.1 SODO Segment

The SODO Segment is between South Forest Street and South Holgate Street and is within an industrial district. The closest residential properties are nearly 0.5 mile away and east of Interstate 5. Therefore, no construction noise impacts are expected.

6.2.3.2 Duwamish Segment

Properties within the Duwamish Segment are primarily industrial. There is a residential district west of West Marginal Way Southwest and south of the West Seattle Bridge in Pigeon Point. Secret Studio Records/Studio 1208 is the only FTA Category 1 land use for noise in the Duwamish Segment. The Bootstrap Music Company is also in this segment but is located near major heavy trucking routes and freight train tracks and therefore is not considered noise-sensitive.

All three Duwamish Segment Build Alternatives would include construction of elevated guideway from the SODO Segment and a bridge over the Duwamish Waterway. Preferred Alternative DUW-1a and Option DUW-1b would cross the Duwamish Waterway on a new bridge south of the West Seattle Bridge and transition into a retained cut at the north side of Pigeon Point before connecting to the Delridge Segment. Alternative DUW-2 would construct a new bridge to the north of the West Seattle Bridge and remain elevated until connecting to the Delridge Segment.

The closest residential properties are approximately 100 feet from Preferred Alternative DUW-1a and Option DUW-1b. These properties would be near the transition from elevated structures to retained cut and would experience construction noise from both types of construction. Sound levels from elevated construction are expected to be up to 81 dBA and up to 83 dBA during retained-cut construction. These activities are expected to exceed the city’s construction noise limits and result in noise impacts at nearby residential properties around Pigeon Point.

Because of the proximity of construction activities, the Bootstrap Music Company could experience sound levels exceeding 92 dBA during construction of the elevated guideway under Preferred Alternative DUW-1a and Option DUW-1b. Although sound levels are not expected to exceed City of Seattle construction noise limits, construction noise may temporally affect operations within the Bootstrap Music Company during periods of heavy construction. Under Alternative DUW-2, the Bootstrap Music Company could experience construction noise up to 66 dBA during the construction of the elevated guideway, which is unlikely to impact its operations given the existing noise environment.

Although Secret Studio Records/Studio 1208 on the southwest corner of 23rd Avenue Southwest and Southwest Andover Street is located in the Duwamish Segment, construction noise at this FTA Category 1 receiver would come from project construction in the Delridge Segment and is discussed in Section 6.2.3.3.

Alternative DUW-2 is approximately 500 feet from residential properties and does not require retained-cut construction. Because Alternative DUW-2 is farther from residential properties than the other alternatives, it is expected to result in the least noise impacts.

Bridge construction would likely take place in industrial districts on the shore of the Duwamish Waterway and Harbor Island, or in the water. The loudest sound levels would likely be generated from pile-driving during construction of the temporary work trestle, piles, and cofferdams. Sound levels during pile-driving are expected to exceed 101 dBA at 50 feet from the work. Nearby noise-sensitive properties may experience sound levels up to 78 dBA during pile-driving. Construction of the bridge may take 3 to 4 years to complete.

Nighttime construction may be required at locations along the elevated guideway where it crosses over roadways, such as the West Seattle Bridge and West Marginal Way Southwest. A noise variance for any nighttime work would be requested from the City of Seattle.

6.2.3.3 Delridge Segment

The Delridge Segment is mostly made up of residential districts. Industrial districts are north of Southwest Andover Street and a commercial district is between Southwest Andover Street and residences south of Southwest Yancy Street. As previously described, although Secret Studio Records/Studio 1208 is in the Duwamish Segment, due to its location and nearby hills, it would experience higher levels of construction noise from construction occurring within the Delridge Segment than the Duwamish Segment.

All of the Delridge Segment alternatives would include elevated guideway between the Duwamish Segment and the station. The location of the station varies between alternatives and could be north of Southwest Andover Street to the west of Delridge Way Southwest, on Delridge Way Southwest between Southwest Andover Street and Southwest Dakota Street, or between Southwest Dakota Street and Southwest Genesee Street. Nighttime construction could be necessary in areas crossing over roadways, requiring a noise variance.

West of the station the light rail would remain elevated to the West Seattle Junction Segment under Alternative DEL-1a, Option DEL-1b, Alternative DEL-3, and Alternative DEL-5. The alignment would enter a retained cut for Preferred Option DEL-6b and Alternative DEL-6a near 32nd Avenue Southwest. Alternative DEL-2a and Alternative DEL-4 would transition to a short section of retained cut near 30th Avenue Southwest.

All alternatives would require guideway construction within 50 feet of residential properties. This may result in sound levels of up to 87 dBA and would likely exceed Seattle construction sound limits.

City of Seattle construction noise limits would likely be met at Secret Studio Records/Studio 1208 under all alternatives. Construction of Preferred Option DEL-6b, Alternative DEL-5, Alternative DEL-6a, and Alternative DEL-7 are expected to generate noise levels up to 70 dBA at Secret Studio Records/Studio 1208. This is lower than the other alternatives that are along Delridge Way, which are expected to generate noise levels up to 75 dBA. Because the distances between Secret Studio Records/Studio 1208 and the Delridge Station under Preferred Option DEL-6b and Alternatives DEL-3, DEL-4, DEL-5, DEL-6a, and DEL-7 are similar, construction of the station is expected to result in similar construction noise levels at Secret Studio Records/Studio 1208 and would be approximately 67 dBA. Station construction under Alternative DEL-1a, Option DEL-1b, Alternative DEL-2a, and Option DEL-2b would be further away from Secret Studio Records/Studio 1208 and would likely result in sound levels of approximately 60 dBA.

Tunnel construction would occur under Alternative DEL-2a, Alternative DEL-4, and Alternative DEL-7. Tunnel portals under Alternative DEL-2a and Alternative DEL-4 would be constructed at Southwest Genesee Street near 30th Avenue Southwest and may take up to 2 years to build. The tunnel portal under Alternative DEL-7 would be constructed near Southwest Andover Street. Tunneling would typically occur 20 to 24 hours per day, 6 to 7 days per week. Nighttime construction may include removing spoils from the site and delivering materials.

Ventilation fans could be necessary to supply fresh air to construction crews working inside the tunnel and would likely operate continuously. Tunnel construction may last for 1 to 2 years.

Tunnel portals constructed under all alternatives would be within residential districts and the closest residential properties would be approximately 50 feet away from construction activities. Sound levels at these properties may by up to 86 dBA and exceed the City's construction sound limits and result in noise impacts.

Construction of Preferred Option DEL-6b, Alternative DEL-5, and Alternative DEL-6a may result in the least noise impacts at residential properties because a portion of the alignment would be within industrial and commercial districts and farther away from noise-sensitive properties than other alternatives. Although most of Alternative DEL-7 would also be within industrial and commercial properties and would include a tunnel, construction at the tunnel portal would be within a residential district, likely include night work, and have a longer construction duration than Preferred Option DEL-6b, Alternative DEL-5, and Alternative DEL-6a.

6.2.3.4 West Seattle Junction Segment

The West Seattle Junction Segment includes residential and commercial districts. Residential properties are throughout the segment and commercial properties are generally between Southwest Alaska Street and Southwest Edmunds Street.

Elevated guideway construction would be necessary to construct the Alternative WSJ-1, Alternative WSJ-2, and northern portion of Alternative WSJ-4. The Avalon Station would be elevated under these three alternatives. Nighttime construction may be required when crossing over roadways. The elevated guideway and the construction of Avalon Station may take 2 to 3 years to complete.

Properties within residential districts would be within 50 feet of elevated construction. These properties would likely experience construction sound levels of up to 87 dBA which exceeds Seattle construction noise limits and would result in noise impacts.

Some West Seattle Junction alternatives would include construction of a tunnel and underground Alaska Junction Station. Construction of the underground station would use cut-and-cover construction and take 4 to 6 years to build.

Because the tunnels in the West Seattle Junction Segment are relatively short and shallow, the tunnel could be built using a tunnel boring machine or sequential excavation mining. Both tunneling methods would require ventilation fans on the surface to supply fresh air into the tunnel and would run continuously. Nighttime work would likely be necessary to remove spoils from the portal area. Tunneling may take 1 to 2 years to construct.

The tunnel options with tunnel portals close to or within residential districts in the West Seattle Junction Segment would be Preferred Option WSJ-5b, Alternative WSJ-4, and Alternative WSJ-5a. Residential properties would be approximately 50 feet from the tunnel portals and may experience sound levels up to 86 dBA. These sound levels would exceed the city's construction sound limits and would result in noise impacts.

Alternative WSJ-1 and Alternative WSJ-2 may result in less impacts at noise-sensitive properties than other alternatives which require tunneling. Although tunneling would take place underground, night work at the tunnel portals may last several years, whereas elevated construction may only require night work when crossing over roadways and the overall construction duration may be less than construction of a below-grade station and tunnel.

6.3 Operational Vibration Impacts

This section presents the results of the detailed assessment of vibration impacts from train operations. The assessment was based on the FTA methodology discussed in Section 4.2, Vibration Assumptions and Methods. The inputs for the assessment include distance from the receivers to the tracks, train speeds, track type, and other relevant information such as proximity to special trackwork.

6.3.1 No Build Alternative

The No Build Alternative would not result in any change to the existing vibration environment. There are no projected vibration impacts for the No Build Alternative.

6.3.2 Build Alternatives

Tables 6-6 through 6-8 and Figures 6-4 through 6-6 summarize the number of groundborne noise and vibration impacts by alternative for segments where impacts were predicted. A discussion of key differences between alternatives follows. Attachment N.3E includes detailed maps that show the locations of sensitive receivers with projected impact and Attachment N.3G contains tables with the projected vibration and groundborne noise levels for all sensitive receivers.

6.3.2.1 SODO Segment

Based on the land use review, there were no FTA vibration-sensitive properties in the SODO Segment; therefore, no vibration impacts were identified.

6.3.2.2 Duwamish Segment

Vibration impacts are shown in Table 6-6 and on Figure 6-4. Groundborne noise impacts were not assessed for elevated alternatives. Preferred Alternative DUW-1a is the only alternative with projected impacts in the Duwamish Segment, and the projected impacts are near crossovers. Crossovers are special trackwork that can increase predicted vibration levels by 5 to 10 decibels. An impact is projected at Fire Station 14 near the turnout at the entrance to the Operations and Maintenance Facility Central. When connecting to Preferred Option DEL-6b or Alternative DEL-7, an impact is also projected at a single-family residence near the crossover east of Delridge Way Southwest near the West Seattle Bridge on-ramp. When connecting to Alternative DEL-5 or Alternative DEL-6a, the crossover located near Delridge Way Southwest is further from sensitive receivers and no impact is projected at that crossover location.

Alternative DUW-1b and Alternative DUW-2 in the Duwamish Segment are not projected to have impacts, because they do not have special trackwork as close to sensitive receivers. All alternatives and options in this segment would be mostly elevated, which reduces vibration levels by about 10 dB compared with at-grade track. Therefore, there are few impacts in this segment compared to the West Seattle Junction and Delridge segments.

Alternative DUW-2 is near Harbor Island Machine Works, a precision manufacturing company with vibration-sensitive equipment, but the projected vibration level from light rail operations would not exceed the applicable limit.

Table 6-6. Summary of Vibration Impacts by Alternative in the Duwamish Segment

Alternatives and Design Options	Category 1 Vibration Impacts	Category 2 Vibration Impacts	Category 3 Vibration Impacts	Total Vibration Impacts	Distance Range (feet) [a]	Range of exceedance (dB) [b]
Preferred South Crossing Alternative (DUW-1a)	**0**	**1 to 2**	**0**	**1 to 2**	**67 to 172**	**0 to 1**
South Crossing South Edge Crossing Alignment Option (DUW-1b)	0	0	0	0	Not applicable	Not applicable
North Crossing Alternative (DUW-2)	0	0	0	0	Not applicable	Not applicable

Note: Numbers presented are individual residences (including units at multi-family structures) for FTA Category 2 land uses and number of structures for FTA Category 1 and 3 land uses.

[a] The slant distance between the near track and the façade of the sensitive receivers with impact, in feet. For alternatives with no impact, no distance is provided.

[b] The decibel amount by which the vibration (VdB) or groundborne noise (dBA) would exceed the applicable criteria. For alternatives with no impact, no value is provided.

6.3.2.3 Delridge Segment

Vibration and groundborne noise impacts are shown in Table 6-7 and on Figure 6-5. Groundborne noise impacts were not assessed for elevated alternatives. Preferred Option DEL-6b would have impacts at one single-family residence near the intersection of Southwest Andover Street and Southwest Avalon Way.

Alternative DEL-1 and Alternative DEL-3 would have the most impacts in the Delridge Segment. The impacts would be at the same multi-family building, the Golden Tee Apartments, near the intersection of Southwest Genesee Street and Southwest Avalon Way.

Option DEL-1b, Alternative DEL-2a, Option DEL-2b, and Alternative DEL-4 would not have any impacts. The sensitive receivers closest to these options would be displaced as part of the project and the projected vibration levels at the nearest remaining sensitive receivers would be below the criteria.

For Alternative DEL-5 and Alternative DEL-6a, there would be impacts at the residences closest to the alignment. Alternative DEL-6a would impact several single-family residences. Alternative DEL-5 would impact a multi-family building at 30th Avenue Southwest and Southwest Dakota Street that has a greater number of dwelling units and therefore would have more impacts.

For Alternative DEL-7, there would be groundborne noise impacts at the residences near the tunnel portal. All of the impacts for Alternative DEL-7 would be at single-family residences.

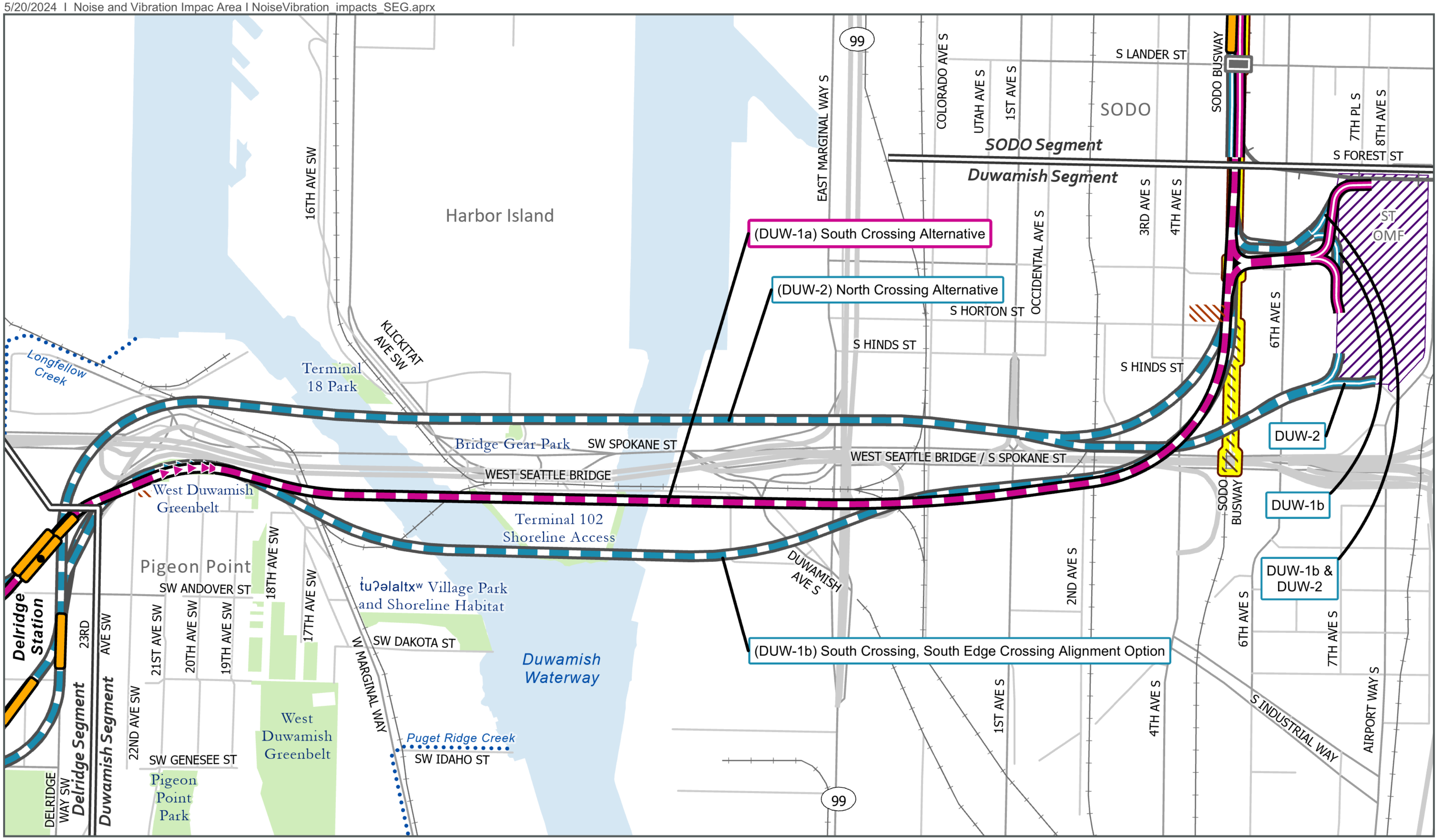
Table 6-7. Summary of Vibration Impacts by Alternative in the Delridge Segment

Alternatives and Design Options	Category 1 Vibration Impacts	Category 2 Vibration Impacts	Category 2 Groundborne Noise Impacts	Category 3 Vibration Impacts	Total Vibration or Groundborne Noise Impacts	Distance Range (feet) [a]	Range of Exceedance (dB) [b]
Preferred Andover Street Station Lower Height South Alignment Option (DEL-6b)	**0**	**1**	**Not applicable**	**0**	**1**	**26**	**1**
Dakota Street Station Alternative (DEL-1a)	0	12	Not applicable	0	12	44	<1
Dakota Street Station North Alignment Option (DEL-1b)	0	0	Not applicable	0	0	Not applicable	Not applicable
Dakota Street Station Lower Height Alternative (DEL-2a)	0	0	Not applicable	0	0	Not applicable	Not applicable
Dakota Street Station Lower Height North Alignment Option (DEL-2b)	0	0	Not applicable	0	0	Not applicable	Not applicable
Delridge Way Station Alternative (DEL-3)	0	12	Not applicable	0	12	42	<1
Delridge Way Station Lower Height Alternative (DEL-4)	0	0	Not applicable	0	0	Not applicable	Not applicable
Andover Street Station Alternative (DEL-5)	0	9	Not applicable	0	9	27	<1
Andover Street Station Lower Height Alternative (DEL-6a)	0	3	Not applicable	0	3	50 to 76	1 to 4
Andover Street Station Lower Height No Avalon Station Tunnel Connection Alternative (DEL-7)	0	0	9	0	9	54 to 124	0 to 8

Note: Numbers presented are individual residences (including units at multi-family structures) for FTA Category 2 land uses and number of structures for FTA Category 1 and 3 land uses.

[a] The slant distance between the near track and the façade of the sensitive receivers with impact, in feet. For alternatives with no impact, no distance is provided.

[b] The decibel amount by which the vibration (VdB) or groundborne noise (dBA) would exceed the applicable criteria. For alternatives with no impact, no value is provided.



Source: City of Seattle, King County (2023).

Preferred Alternative
- Elevated
- Retained Cut
- At-Grade

Other Alternatives
- Elevated
- Retained Cut
- At-Grade

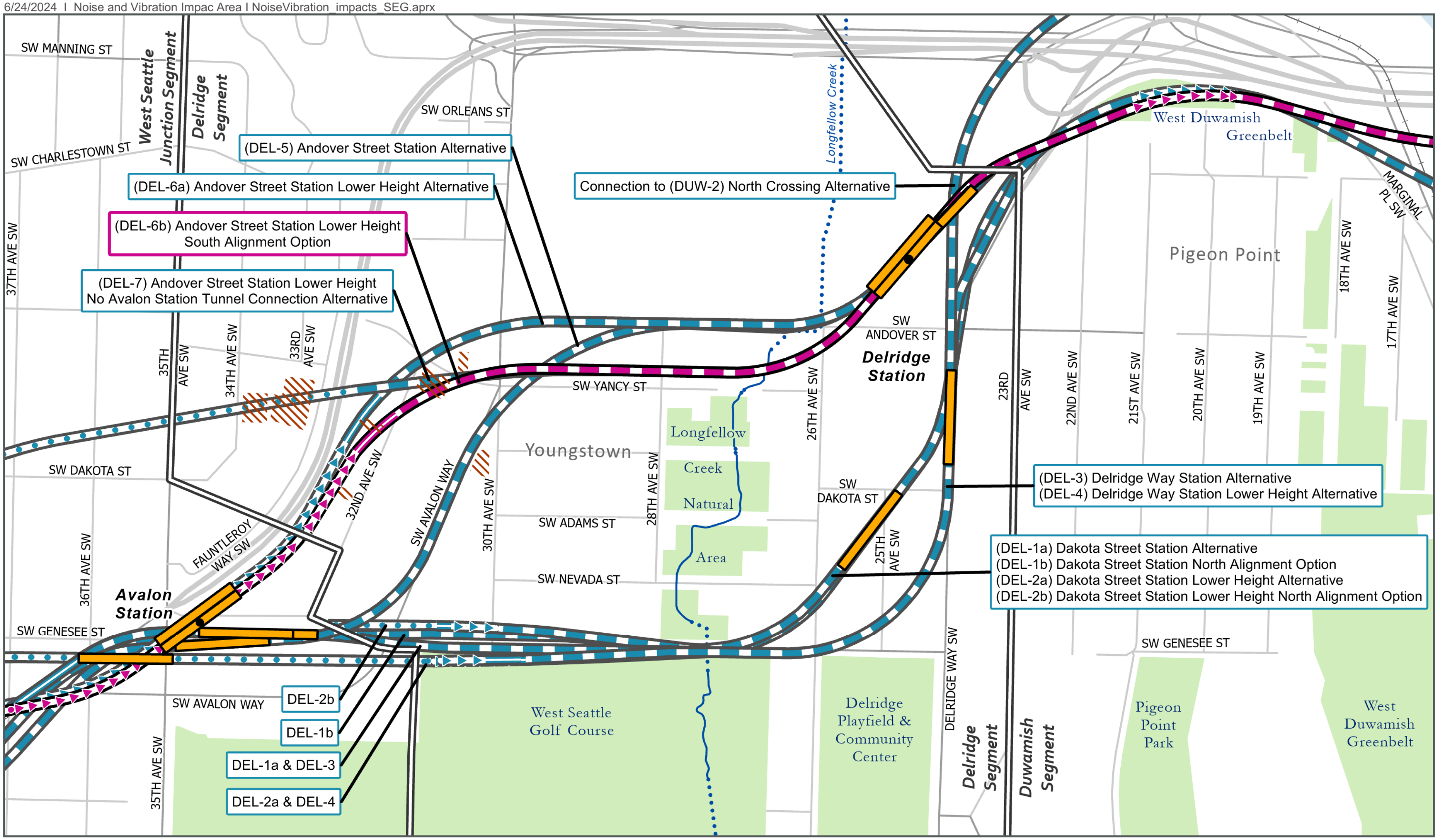
Station (● *Indicates Preferred Alternative*)
- New

- Segment Line
- Existing Link Light Rail
- Railroad
- SODO Busway
- Proposed Overpass
- Sound Transit Operations and Maintenance Facility (ST OMF)
- Piped Stream
- Park
- Area of Vibration or Groundborne Noise Impact

FIGURE 6-4
Vibration Impacts (before mitigation)
Duwamish Segment

West Seattle Link Extension

0 500 1,000 Feet
N



Source: City of Seattle, King County (2023).

Preferred Alternative

- Elevated
- Tunnel
- At-Grade
- Retained Cut

Other Alternatives

- Elevated
- Tunnel
- At-Grade
- Retained Cut

Station (● *Indicates Preferred Alternative*)

- New

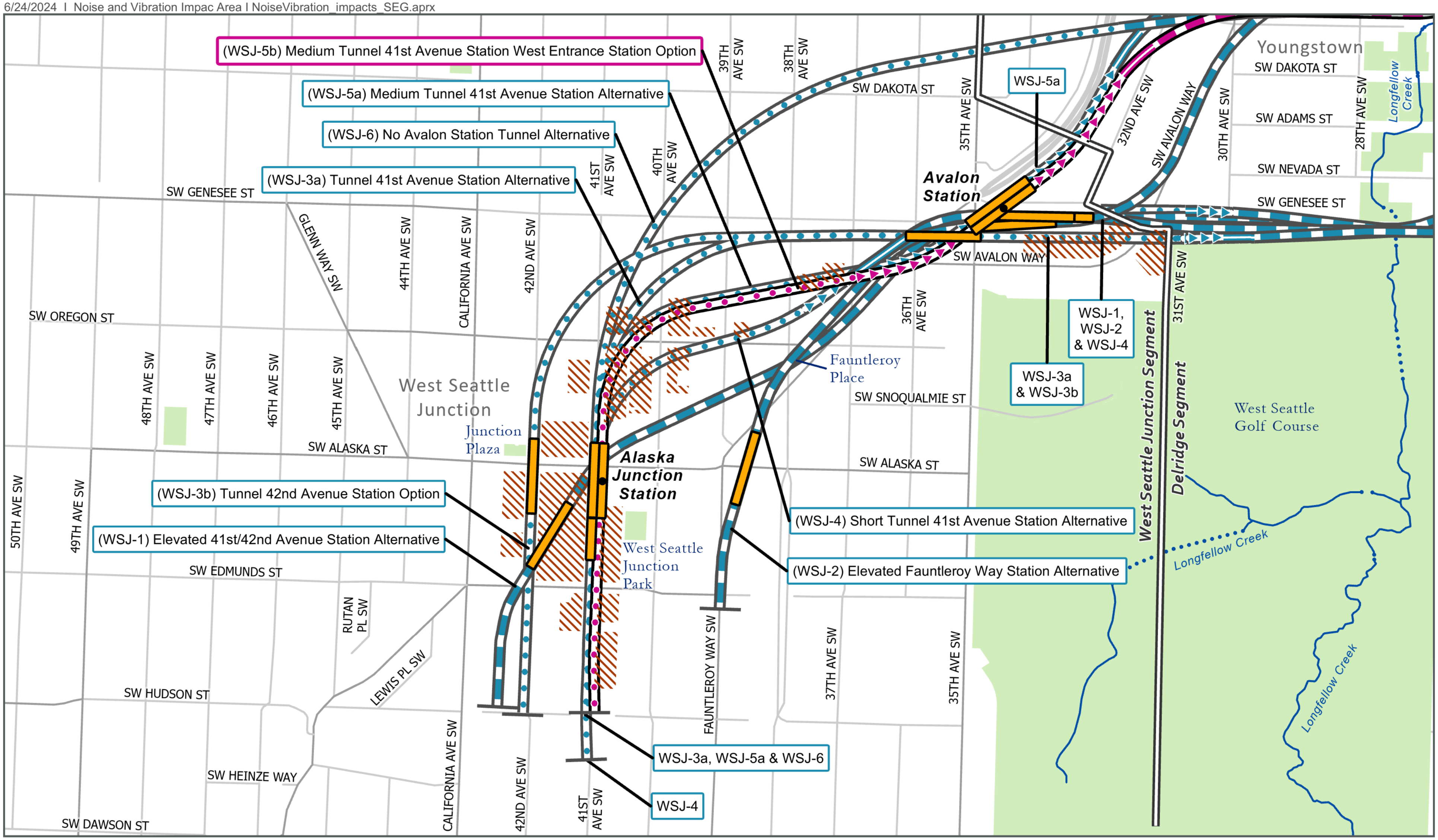
- Segment Line
- Railroad
- Stream
- Piped Stream
- Park

- Area of Vibration or Groundborne Noise Impact

0 500 1,000 Feet N

FIGURE 6-5
Vibration Impacts (before mitigation)
Delridge Segment

West Seattle Link Extension



Source: City of Seattle, King County (2023).

Preferred Alternative
- Elevated
- Tunnel
- At-Grade
- Retained Cut

Other Alternatives
- Elevated
- Tunnel
- At-Grade
- Retained Cut

Station (● *Indicates Preferred Alternative*)
- New

- Segment Line
- Stream
- Piped Stream
- Park
- Area of Vibration or Groundborne Noise Impact

0 500 1,000 Feet
N

FIGURE 6-6
Vibration Impacts (before mitigation)
West Seattle Junction Segment

West Seattle Link Extension

6.3.2.4 West Seattle Junction Segment

Groundborne noise and vibration impacts are shown in Table 6-8 and on Figure 6-6. In the West Seattle Junction Segment, the tunnel alternatives would have more impacts than the elevated alternatives because the elevated structures would reduce vibration levels by about 10 dB. All of the impacts for the tunnel alternatives would be from groundborne noise.

Preferred Option WSJ-5 would have impacts near the crossover south of Alaska Junction Station and where the tunnel is shallowest near the tunnel portal and along the curve.

Option WSJ-3b would have the most impacts, which would be concentrated in multi-family buildings along 42nd Avenue Southwest near Southwest Alaska Street and east of Avalon Station along Southwest Avalon Way. Alternative WSJ-2 would have no impacts because of the vibration reduction provided by the elevated structure.

Alternative WSJ-1 would have impacts near a crossover north of the Alaska Junction Station but would have a low number of impacts overall because of the low density of residences near the crossover and the vibration reduction provided by the elevated structure.

For Alternative WSJ-3a, groundborne noise impacts would occur where the tunnel becomes shallower east of the Avalon Station and near the crossover south of the Alaska Junction Station. Alternative WSJ-3a would have impacts at fewer residential dwelling units when connecting to Option DEL-2b compared to connecting with Alternative DEL-2a because the tunnel would be deeper when connecting to Option DEL-2b.

Option WSJ-3b would have the most impacts, but the projected impacts are concentrated in a few multi-family buildings east of the Avalon Station and south of the Alaska Junction Station near a crossover. Option WSJ-3b would have impacts at fewer residential dwelling units when connecting to Option DEL-2b compared to connecting with Alternative DEL-2a because the tunnel would be deeper when connecting to Option DEL-2b.

Alternative WSJ-5a would have a lower number of impacts compared to Alternative WSJ-4 and Alternative WSJ-6. All three alternatives would have impacts at the residences near crossover locations and where the tunnel is shallowest. There are differences in the displacements required for construction of the Alaska Junction Station between the alternatives that affect large multi-family buildings and results in differences in the number of vibration or groundborne noise impacts. There are also differences in where the alternatives are shallowest as they approach different portal locations.

Table 6-8. Summary of Groundborne Noise and Vibration Impacts by Alternative in the West Seattle Junction Segment

Alternatives and Design Options	Category 1 Vibration or Groundborne Noise Impacts	Category 2 Vibration Impacts	Category 2 Groundborne Noise Impacts	Category 3 Vibration or Groundborne Noise Impacts	Total Vibration or Groundborne Noise Impacts	Distance Range (feet) [a]	Range of Exceedance (dB) [b]
Preferred Medium Tunnel 41st Avenue Station West Entrance Station Option (WSJ-5b)	**0**	**0**	**158**	**0**	**158**	**57 to 106**	**0 to 8**
Elevated 41st/42nd Avenue Station (WSJ-1)	0	7	Not applicable [c]	0	7	120 to 186	1 to 2
Elevated Fauntleroy Way Station (WSJ-2)	0	0	Not applicable [c]	0	0	Not applicable	Not applicable
Tunnel 41st Avenue Station (WSJ-3a)	0	0	24 to 199	0	24 to 199	64 to 130	0 to 6
Tunnel 42nd Avenue Station Option (WSJ-3b)	0	0	269 to 430	0	269 to 430	64 to 95	0 to 7
Short Tunnel 41st Avenue Station (WSJ-4)	0	0	153	0	153	55 to 106	0 to 10
Medium Tunnel 41st Avenue Station (WSJ-5a)	0	0	79	0	79	57 to 106	0 to 5
No Avalon Station Tunnel (WSJ-6)	0	0	144	0	144	81 to 106	0 to 6

Notes:

Numbers presented are individual residences (including units at multi-family structures) for FTA Category 2 land uses and number of structures for FTA Category 1 and 3 land uses.

Ranges reflect differences from connecting to different alternatives in adjacent segments.

[a] The slant distance between the near track and the façade of the sensitive receivers with impact, in feet. For alternatives with no impact, no distance is provided.

[b] The decibel amount by which the vibration (VdB) or groundborne noise (dBA) would exceed the applicable criteria. For alternatives with no impact, no distance is provided.

[c] Groundborne noise is not assessed for elevated alternatives.

6.4 Construction Vibration Impacts

As discussed in Section 4.2.2, Construction Vibration Prediction Methods, construction vibration generally falls into the categories of tunneling activities and surface construction activities. The vibration from tunneling muck and support trains are compared to the FTA criteria for operations because this can be a relatively long-term activity. For surface construction activities that are temporary in nature, the construction vibration criteria from Section 3.2.3, Construction Vibration Criteria, are applied. The construction vibration criteria were developed to avoid potential damage risk to buildings, while the operational vibration criteria were developed to avoid annoyance for Category 2 and Category 3 sensitive receivers. The construction vibration criteria are the thresholds for the potential of superficial damage, such as cracks in plaster, and are not the threshold at which structural damage would occur.

Category 1 and special-use buildings are evaluated using the FTA criteria for operations for all construction activities, because exceedances of those limits may interfere with operations inside the building. The construction vibration criteria also apply to historic buildings, which may be particularly susceptible to construction damage. Construction vibration impacts specific to historic buildings were not assessed. Historic buildings should be taken into account when updating the construction vibration assessment during final design when more information on construction means and methods is known.

6.4.1 Tunneling Vibration Impacts

The three major sources of vibration from tunneling are the cutterhead operation, thrust jack retraction during concrete liner installation, and operation of the supply train. The range of vibration levels expected from the three activities and the relevant criteria are shown on Figures 4-7 to 4-9. As shown in the figures, the range of expected levels for all three activities would be below the operational criteria for annoyance for Category 2 (residential) land uses, and therefore would also be below the criteria for institutional land uses, which have a higher limit.

There are no Category 1 or special-use buildings near tunnel alternatives in the West Seattle Link Extension study area. The expected vibration levels from tunneling would be below the operational criteria for annoyance for Category 2 (residential) and Category 3 (institutional) land uses. Therefore, there would be no vibration impact from tunneling in the West Seattle Link Extension study area. The predicted levels from tunneling activities relative to the Category 2 and Category 3 limits are shown on Figures 4-7 through 4-9. The predicted levels from tunneling operations are also below the most restrictive criteria for minor cosmetic building damage.

Groundborne noise has been evaluated for tunneling operations because there is no airborne noise path. Thresholds for groundborne noise due to train operations have been applied as the annoyance thresholds for tunneling activities. The thresholds are 35 dBA and 40 dBA for Category 2 and Category 3 land uses, respectively. Table 6-9 shows the range of expected groundborne noise levels based on data measured under the University of Washington campus presented in Section 4.2.2, Construction Vibration Prediction Methods, which show very high variability. Vibration from the tunnel boring machine cutterhead may reach as high as 40 dBA, which would exceed the criteria for Category 2 land uses and equal the criteria for Category 3 land uses. The highest groundborne noise levels are typically caused by very localized underground features such as cobbles, so it is not possible to identify precise locations where the groundborne noise criteria are most likely to be exceeded. Effects from the cutterhead would likely only last up to 1 week as the cutterhead makes progress along the tunnel.

Mitigation measures are discussed in Section 7.4, Construction Vibration Mitigation.

Table 6-9. Range of Predicted Groundborne Noise Levels During Tunneling

Vibration Source	Groundborne Noise Prediction (dBA) [a]
Tunnel Boring Machine Cutterhead	14 to 40
Thrust Jack Retraction	13 to 29
Supply Train with steel wheels and jointed rails	24 to 28

[a] Range is based on measured data from 0 to 200 feet from tunnel.

6.4.2 Surface Construction Vibration Impacts

The primary concern from construction activities is the potential for damage to buildings. Because the details of the construction means and methods for this project may change from what is described in Chapter 2, Alternatives Evaluated, of the Final EIS and there are several alternatives, the construction vibration analysis focused on determining the distance beyond which the damage risk criteria and annoyance criteria would not be exceeded.

Table 6-10 shows the distance at which vibration from different pieces of construction equipment is expected to be equal to different thresholds for potential damage, rounded up to the nearest 10 feet. The highest vibration-generating construction activity that could occur would be pile-driving. Several receivers have the potential to be impacted by pile-driving in areas where bridge construction, elevated track guideway, or retained cut guideway is planned.

Table 6-10. Distance to Vibration Thresholds for Construction Equipment Pieces

Equipment	Peak Particle Velocity Reference Level at 25 feet (inch per second)	Distance to 0.5 inch per second Damage Criteria (feet) [a]	Distance to 0.2 inch per second Damage Criteria (feet) [a]	Distance to Category 3 Annoyance Criteria (feet) [b]	Distance to Category 2 Annoyance Criteria (feet) [b]
Impact Pile Driver [c]	0.644 to 1.518	30 to 60	60 to 100	240 to 420	300 to 530
Sonic Pile Driver [c]	0.17 to 0.734	20 to 40	30 to 60	100 to 260	130 to 330
Hoe Ram	0.089	10	20	70	80
Large Bulldozer	0.089	10	20	70	80
Caisson Drilling	0.089	10	20	70	80
Loaded Trucks	0.076	10	20	60	80
Jackhammer	0.035	10	10	40	50
Small Bulldozer	0.003	10	5	10	10

[a] Thresholds defined in Section 3.2.2, Groundborne Noise Criteria: 0.5 inch per second for reinforced concrete, steel, or timber and 0.2 inch per second for nonengineered timber and masonry buildings.

[b] Annoyance limits of 75 VdB for Category 3, and 72 VdB for Category 2 on projects with frequent events (>70 per day).

[c] Reference levels and distances cover a range from typical to high amounts of vibration from the equipment.

The project may use impact or sonic (vibratory) pile-driving for the construction of elevated guideways, retained cut guideways, and the bridge over the Duwamish Waterway. Pile-driving would result in a risk of damage to nonengineered timber and masonry buildings (0.2 inch per second threshold) at structures within 100 feet of impact pile-driving and within 60 feet of sonic pile-driving. When structures are within these distances, pile-driving should be avoided in favor of alternative construction methods such as drilled shaft foundations or shallow spread footings.

Within the SODO Segment, there may be structures located within 100 feet of pile locations for the elevated alternative (Alternative SODO-2). There may be structures within 100 feet of pile locations for the retained cut sections north of South Walker Street for Preferred Option SODO-1c, Alternative SODO-1a, and Option SODO-1b.

Within the Duwamish Segment, pile-driving may be used for the new light rail bridge over the Duwamish Waterway, elevated guideways, and the retained cut section along the Pigeon Point neighborhood. For Preferred Alternative DUW-1a and Option DUW-1b, single-family residences in the Pigeon Point and Riverside neighborhoods west of the waterway may be within 100 feet of pile locations. For Preferred Alternative DUW-1a, some of the Harbor Marina buildings on Harbor Island may be within 100 feet of pile locations. For Option DUW-1b, there are unlikely to be any buildings within 100 feet of pile locations on Harbor Island. For Alternative DUW-2, the Harbor Island Machine Works and Meltec buildings on Harbor Island are likely to be within 100 feet of pile locations.

Within the Delridge Segment, pile-driving may be used for the elevated guideway for all alternatives and for retained cut sections near tunnel portals for some alternatives. For Alternative DEL-1a, Option DEL-1b, Alternative DEL-2a, Option DEL-2b, Alternative DEL-3, and Alternative DEL-4, the closest buildings to the guideway along Southwest Genesee Street and Delridge Way Southwest may be within 100 feet of pile locations for elevated structures. For Preferred Option DEL-6b, Alternative DEL-6a, and Alternative DEL-7, the closest structures along Southwest Yancy Street may be within 100 feet of the pile locations for elevated structures. For Alternative DEL-2a, Option DEL-2b, and Alternative DEL-4, the closest buildings to the retained cut near the tunnel portal locations east of Avalon Way Southwest may be within 100 feet of pile locations. For Preferred Option DEL-6b and Alternative DEL-6a, the closest residences to the retained cut section between the West Seattle Bridge and 32nd Avenue Southwest may be within 100 feet of pile locations.

Within the West Seattle Junction Segment, pile-driving may be used for the elevated guideway for Alternative WSJ-1 or Alternative WSJ-2. For both alternatives, there may be buildings within 100 feet of the pile locations near Fauntleroy Way Southwest; for Alternative WSJ-1, there may also be buildings within 100 feet of the pile locations near 42nd Avenue Southwest. Pile-driving may also be used for retained cut sections near the tunnel portals for Preferred Option WSJ-5b, Alternative WSJ-4, and Alternative WSJ-5a.

The results in Table 6-10 show that equipment other than pile drivers can operate without risk of damage at distances of 10 feet or greater from reinforced concrete buildings (0.5 inch per second threshold) and 20 feet or greater from nonengineered timber and masonry buildings (0.2 inch per second threshold), which are the most common types of buildings in the study area. The mitigation measures discussed in Section 7.4.1 should be considered when operating equipment within the damage criteria distances listed in Table 6-10. Plans to operate within these minimum distances should be avoided, as practical, when developing construction means and methods.

During final design, a construction vibration impact assessment would be developed to address all Category 1 receivers and locations where operations may be within these minimum distances and consider use of the vibration-reducing measures discussed in Section 7.4. Category 1 receivers, where high levels of vibration may disrupt business operations, are Harbor Island Machine Works and Secret Studio Records. In the Duwamish Segment, the Harbor Island Machine Works on Harbor Island is likely to be within 100 feet of pile locations for Alternative DUW-2. The Bootstrap Music Company, a music rehearsal space, is located near the east end of the West Seattle Bridge in the Duwamish Segment and is likely to be within 100 feet of pile locations for Preferred Alternative DUW-1a. The Bootstrap Music Company is not considered a Category 1 land use because it is compatible with noise and vibration levels generated by operational light rail; however, higher levels of vibration and groundborne noise generated by construction might be noticeable in the building. In the Delridge Segment, the Secret Studio Records/Studio 1208 recording studio is likely to be within 300 feet of pile locations for Alternative DEL-1a, Option DEL-1b, Alternative DEL-2a, Option DEL-2b, Alternative DEL-3, and Alternative DEL-4, which is within a distance that vibration or groundborne noise generated by pile-driving may affect the operations of a recording studio.

6.5 Indirect Impacts

Indirect noise and vibration impacts include increased noise and/or vibration levels near the project that could be associated with transit-oriented development, typically traffic and construction noise and vibration. Although noise associated with future development could increase noise in the project corridor, any increase would be expected to be minimal and any new developments would be required to meet the City of Seattle noise regulations. Most vehicle traffic and other sources of environmental vibration are below the levels of human perception and would not constitute an indirect impact.

6.6 Cumulative Impacts

6.6.1 Operation

The FTA's methodology for noise and vibration analysis reflects both cumulative ambient noise conditions from land uses and activities from past and present activities in combination with project-specific noise and vibration impacts. All project noise impacts could be mitigated depending on the alternatives chosen. Most vibration impacts can also be mitigated; however, there could be residual vibration impacts in some segments.

The light rail vibration might occur concurrently with vibration from heavy trucks on rough roads and local construction activities. Cumulative vibration levels in most areas are not expected to differ from existing vibration levels. Exceptions to this would include areas that have extremely rough roadways with potholes or cracks, which would increase vibration levels from passing trucks and other heavy vehicles, and areas near active construction sites where equipment could cause short-term increases in vibration levels.

No other reasonably foreseeable future actions are expected to cause notable vibration impacts during project operation, so cumulative vibration impacts are not expected. Although Sound Transit is committed to mitigating project noise impacts, light rail would still create a new noise source and, therefore, would contribute to cumulative noise in the project corridor. In addition, the indirect impact of the project, combined with local land use policies, could attract more development around rail stations, which might result in more intense urban activities in some station areas, therefore adding cumulative noise to the surroundings.

6.6.2 Construction

During construction, the project would contribute noise and vibration impacts along with other nearby transportation and private development construction projects, and cumulative impacts would be anticipated. Any construction activities would have to comply with the City of Seattle's noise regulations or require a noise variance from the City. Where necessary, Sound Transit would monitor noise and vibration during construction to minimize related disturbances on residential and other sensitive areas and work with other adjacent projects to limit nighttime noise and vibration impacts.

7 NOISE AND VIBRATION MITIGATION MEASURES

For locations where Sound Transit has identified potential noise impacts, mitigation measures will be considered and reviewed using Resolution No. R2023-15, Sound Transit's light rail Link Noise and Vibration Policy (Sound Transit 2023). Under this policy, potential mitigation measures will be considered for all noise impacts where reasonable and feasible mitigation is available.

Sound Transit's noise mitigation policy is to mitigate impacts beginning with source treatment, followed by treatments in the noise path. If source and path treatments are not sufficient to mitigate the impact, Sound Transit will evaluate and implement sound insulation at affected properties where the existing building does not already achieve sufficient exterior-to-interior reduction of noise levels. Sound Transit practice is to mitigate both FTA moderate and severe impacts. Detailed tables of noise levels for each receiver location, before and after mitigation, are provided in Attachment N.3F.

Sections 7.1.1, Transit Noise Mitigation Approaches, and 7.1.2, Traffic Noise Mitigation Approaches, introduce the mitigation strategies normally used for light rail projects. Following this introduction, Section 7.1.3, Proposed Operational Noise Mitigation, presents the mitigation strategies and measures proposed for the West Seattle Link Extension. Mitigation for noise related to construction is discussed in Section 7.2.

Also consistent with Sound Transit's policy, where potential vibration impacts are identified, vibration mitigation measures will be considered. Vibration mitigation measures focus on reducing the source of vibration, with path and building treatment being considered as secondary measures. Section 7.3.1, Vibration Mitigation Approaches, introduces the vibration mitigation strategies normally used for light rail projects. The vibration mitigation measures and strategies proposed for the project are presented in Section 7.3.2, Proposed Operational Vibration Mitigation. Section 7.4 discusses construction vibration mitigation measures for surface construction and tunneling.

During final design, all impacts and potential mitigation measures will be reviewed for verification. If it is discovered that the mitigation could be achieved by less costly means, or if refined detailed analysis shows reduced or no impact, the mitigation measure may be downgraded or eliminated.

7.1 Operational Noise Mitigation

This section discusses mitigation for noise generated by the operation of the West Seattle Link Extension. Potential mitigation measures for construction noise are discussed in Section 7.2, Construction Noise Mitigation.

7.1.1 Transit Noise Mitigation Approaches

Several types of noise mitigation measures can be used to reduce noise levels and mitigate noise impacts. First, to minimize noise effects and the subsequent need for their mitigation, Sound Transit has incorporated several noise-reducing project design elements into the project. These include the noise-reducing effects from elevated structures and retained-cut segments where project-related design reduces noise from light rail operations through physical shielding. For areas where these types of design options are not available, other forms of mitigation are considered and are discussed in order of application in the following sections (e.g., source, path, or receiver).

7.1.1.1 Noise Source Mitigation

One of the most effective forms of noise mitigation is to reduce noise at the source. One form of source noise reduction is using light rail vehicles with low noise levels. Sound Transit has purchased state-of-the-art, lower-noise vehicles equipped with noise-reducing wheel skirts covering the wheel-rail interface. Several additional operational measures can also be used to reduce noise levels at the source. Table 4-1 lists operational and maintenance measures that Sound Transit performs on a regular basis and the benefits that these measures provide. Crossovers, special track work, and adjustments based on track type are provided in Table 7-1. Typical noise reductions for sound walls, elevated acoustical walls, and trench situations are also shown in Table 7-1. Source treatments that Sound Transit is currently using to minimize noise impacts include requiring wheel skirts, maintaining smooth tracks, performing vehicle maintenance and wheel truing, and conducting operator training.

Table 7-1. Light Rail Noise-shielding Adjustments

Track Type	Adjustment in Decibels
Acoustical sound walls on structures between 4 and 6 feet above the top of rail with some going as high as 8 feet. Walls on structures over 8 feet are not normally used because of wind loading and safety concerns.	Typical noise reduction of 6 to 15 dB or more, as predicted using FTA formulas and verified with measured data during normal operations along the existing light rail line in Tukwila.
Sound wall at-grade with an expected height of at least 6 feet above the grade of the guideway. An at-grade sound wall can go as high as 20 feet or more; however, for light rail only mitigation, the typical heights range from 4 to 8 feet.	Typical noise reduction of 4 to 12 dB or more, as predicted using FTA formulas and verified with measured data during normal operations along the Tukwila segment.

Research into methods of reducing wheel squeal noise, including using non-oil-based lubricants (such as water) and friction modifiers, has found such methods effectively reduce or eliminate wheel squeal. The lubricants can be applied by personnel working trackside or by an automated applicator. It is the general policy of Sound Transit to install lubricators on curves with a radius of 600 feet or less and prepare for lubrication on any curves with a radius of less than 1,250 feet near noise-sensitive properties. If wheel squeal is identified after system operation begins, it is possible to add lubricators. There are also some additional considerations that will be reviewed as related to installation and use of lubricants. For example, on some guideways with steeper grades, lubricants on the rails can make track maintenance more difficult and prevent the use of hi-rail vehicles. In some cases, the lubricator may need to be disabled from time to time to facilitate maintenance activities and wayside noise levels and noise from wheel squeal could increase during these brief periods. Once work is completed, the wayside lubricants would be reactivated.

When a light rail train travels over special trackwork for crossovers or turnouts, there is a loud clicking noise as the steel wheels go over the gap between the tracks. This can increase noise levels from the train by as much as 10 dBA compared with a smooth track with no gaps. Mitigation for noise impacts from special trackwork can include relocating the crossover or turnout away from noise-sensitive properties or using special frogs that include gap-closing mechanisms or moveable-point frogs.

With standard rigid frogs, noise and vibration occurs when the wheels pass over the gap in the rail, but a moveable-point frog eliminates the gap and one end of the frog moves in the direction of train travel. Other similar options for reducing noise from special trackwork include spring-rail or flange-bearing frogs. Flange-bearing frogs transfer the vehicle load from the wheel tread to the wheel flange and raise the light rail car up and over the gap, reducing noise and vibration levels. Each of these types of frogs produces noticeably lower noise levels than standard frogs.

Depending on the type of crossover and angle between the crossover and mainline track, special frogs can reduce noise levels between 4 and 8 dBA compared to a standard frog. The type of frogs used for the project would depend on the track type, crossover location, and proximity of noise-sensitive properties.

Relocation of special trackwork to more than 500 feet from noise-sensitive sites also could be used to eliminate the noise impact from the frogs.

7.1.1.2 Path Noise Mitigation

The next type of mitigation considered would be applied between the noise source and receiver. Typical noise path mitigation includes earth berms, sound walls, and buffer zones. Constructing barriers between the light rail tracks and the affected receivers would reduce noise levels by physically blocking the transmission of noise generated by light rail. Barriers can be constructed as walls or earth berms. Berms require more right-of-way than walls and are usually constructed with a 3-to-1 slope. Berms would not be feasible for the project because of topographical conditions and limited right-of-way. Therefore, walls would be used where appropriate.

Two types of sound walls are typically used for transit projects: For at-grade areas, the noise barrier type is a standard concrete wall, while on the elevated guideway, lightweight acoustical walls that place less load on the structure are used. Sound walls should be high enough to break the line of sight between the noise source and the receiver. The typical height for sound walls is 6 to 8 feet (or more) when at-grade and 4 to 6 feet when on elevated structures. Sound walls must also be long enough to prevent flanking of noise around the ends of the walls. Openings in sound walls for driveway connections or intersecting streets greatly reduce the effectiveness of these walls.

Buffer zones are undeveloped open spaces between the noise source and receiver. Buffer zones are created when an agency purchases land or development rights in addition to the normal right-of-way, so that future dwellings cannot be constructed close to the noise source. The West Seattle Link Extension corridor is an urban area that is heavily developed, so creating buffer zones is not a feasible form of noise mitigation because it would require substantially more project-related property acquisition and displacements.

7.1.1.3 Receiver Noise Mitigation

For situations where noise path mitigation would be either unfeasible or ineffective, Sound Transit would consider adding sound insulation to buildings. Sound insulation programs are developed to reduce the interior noise levels in sleeping and living quarters in residential land uses or in noise-sensitive areas such as schools and other institutional uses to within the guidelines set by the U.S. Department of Housing and Urban Development. Under these guidelines, interior noise levels for residential land uses should not exceed an Ldn of 45 dBA, and a form of fresh air exchange must be maintained. The air exchange can be achieved by opening a window or using a ventilation system. Sound insulation is normally only used on older dwellings with single-paned windows or in buildings with double-paned windows that are no longer effective because of leakage. Sound insulation would not reduce exterior noise levels.

7.1.2 Traffic Noise Mitigation Approaches

Potential traffic noise impacts could be mitigated either alone or in conjunction with the light rail mitigation.

In West Seattle, the displacement of residences along 32nd Avenue Southwest under Preferred Option DEL-6b and Alternative DEL-6a required an analysis for traffic noise impacts at residences with increased exposure to West Seattle Bridge traffic noise. The area was analyzed, and no traffic noise impacts were identified due to the steep hillside providing some noise shielding and preventing much of the traffic noise from propagating into the neighborhood. Therefore, no traffic noise mitigation was required.

7.1.3 Proposed Operational Noise Mitigation

For most identified noise impacts, sound walls were the selected method of reducing noise levels, consistent with Sound Transit's Link Noise Mitigation Policy (Sound Transit 2004). Sound walls would be effective at eliminating most predicted noise impacts in the West Seattle Link Extension. Details on the locations and heights for the new walls are provided by project and segment in the following sections. The sound walls presented here were evaluated using 100-foot-long panel segments and the actual wall segments would be much shorter in length, typically 12 to 14 feet long. In addition, during final design, the walls would be optimized further based on any revisions to the project design; therefore, the final wall lengths and heights may vary from those presented here, based on updated design elements and land uses along the corridor. Also, because detailed station design was not available for all stations, and because most station design includes noise-reducing elements, mitigation near some stations is quantified using an equivalent sound wall. In fact, for most stations, these design elements would be sufficient to mitigate noise from light rail operations.

Noise mitigation for the project includes sound walls along the elevated structures and along some at-grade retained-cut segments. Because of the height of some structures in the West Seattle area, not all noise impacts can be mitigated with sound walls. For those sites where sound walls would not be effective, building sound insulation will be examined. Maps showing the locations of sound walls are provided in Attachment N.3D.

7.1.3.1 SODO Segment

There are no FTA noise impacts in the SODO Segment of the West Seattle Link Extension and therefore, no noise mitigation is proposed.

7.1.3.2 Duwamish Segment

Sound walls are summarized by alternative in Tables 7-2 through 7-4. Project station numbering is provided in each of the tables as a reference for the wall locations. With the proposed mitigation, all impacts would be mitigated.

Under Preferred Alternative DUW-1a, Option DUW-1b, and Alternative DUW-2, a 300-foot-long, 4-foot-tall sound wall would be required along the west side of the elevated light rail structure for Seattle Fire Station 14, on 4th Avenue South. Two additional sound walls would also be needed under Preferred Alternative DUW-1a and Option DUW-1b along the Pigeon Point area, east and west of the retained-cut sections of the guideway.

Under Preferred Alternative DUW-1a when connecting to Alternative DEL-6a, additional noise impacts were identified due to the trackway being elevated along a slope in Pigeon Point. There may be an option to install noise walls along the top of the slope; however, due to service access and hillside support, the walls are not included in this analysis and those impacts would be reviewed for sound insulation. If this alternative is selected, additional mitigation analysis would be required.

Under Preferred Alternative DUW-1a, the following sound walls would be needed:

- One 300-foot-long, 4-foot-tall wall on the west side of the structure to provide mitigation to Fire Station 14
- A second, 700-foot-long wall ranging in height from 4 to 8 feet on the south side of the elevated structure to provide mitigation to the east side of the Pigeon Point area
- A third, 800-foot-long, 4- to 8 foot-tall wall on the south side of the structure to provide mitigation for the western slope of Pigeon Point

Table 7-2. Summary of Sound Walls for the Preferred South Crossing Alternative (DUW-1a)

Mitigation	Side of Track	Start Station	End Station	Wall Height	Wall Length
Elevated sound wall	West	174+00	177+00	4 feet	300 feet
At-grade-level and elevated sound wall	East	253+00	260+00	4 to 8 feet	700 feet
Elevated sound wall	East	264+00	Continued in Delridge	4 to 6 feet	800 feet

The sound wall information presented in Table 7-2 would be for connections to Preferred Option DEL-6b and Alternative DEL-7. If connecting to other Delridge Segment alternatives, the sound walls would be similar but the lengths of the at-grade and elevated walls could increase by 100 feet, except for the connection to Alternative DEL-3 and Alternative DEL-4. Because the location of the alignment is farther from the Pigeon Point area, an additional 500 feet of wall would be required for the connection to Alternative DEL-3 and Alternative DEL-4 when compared to Preferred Alternative DUW-1a connecting to Preferred Option DEL-6b and Alternative DEL-7. Wall heights would vary by connection; however, the walls would be 4 to 6 feet, with some short sections of 100 to 200 feet where 8 foot walls may be required.

Table 7-3. Summary of Sound Walls for the South Crossing South Edge Crossing Alignment Option (DUW-1b)

Mitigation	Side of Track	Start Station	End Station	Wall Height	Wall Length
Elevated sound wall	West	174+00	177+00	4 feet	300 feet
Elevated sound wall	East	253+00	262+00	4 to 8 feet	900 feet
Elevated sound wall	East	267+00	Continued in Delridge	4 feet	400 feet

The sound wall information presented in Table 7-3 would be for connections to Alternative DEL-1a, Option DEL-1b, Alternative DEL-2a, Option DEL-2b, Alternative DEL-3, and Alternative DEL-4. If connecting to Preferred Option DEL-6b, Alternative DEL-6a, or Alternative DEL-7, the sound wall length would be slightly shorter and the heights could be slightly different and vary by connection.

Table 7-4. Summary of Sound Walls for the North Crossing Alternative (DUW-2)

Mitigation	Side of Track	Start Station	End Station	Wall Height	Wall Length
Elevated sound wall	West	174+00	177+00	4 feet	300 feet

Under Alternative DUW-2, the only sound wall required is for Fire Station 14, on 4th Avenue South.

7.1.3.3 Delridge Segment

Sound walls are summarized by alternative in Tables 7-5 through 7-14. Project station numbering is provided in each of the tables as a reference for the wall locations.

Under Preferred Option DEL-6b, the following sound walls would be needed:

- A 4- to 8-foot-tall sound wall would begin just south of Delridge Station along the east side of the guideway where it begins to curve toward to the west. The wall would continue through to the West Seattle Junction Segment (2,600 feet).
- A 4- to 6-foot-tall sound wall on the west side of the guideway would begin just east of the intersection of Southwest Andover Street and Southwest Avalon Way where the guideway turns south to travel west of 32nd Avenue Southwest. The 800-foot-long wall would end approximately 400 feet from the West Seattle Junction Segment.
- Noise mitigation would not be required at the Delridge Station as it would be further away from sensitive receivers east of Delridge Way Southwest.

The sound walls are sufficient to mitigate all potential noise impacts under Preferred Option DEL-6b. Table 7-5 summarizes the sound walls for Preferred Option DEL-6b.

Table 7-5. Summary of Sound Walls for the Preferred Andover Street Station Lower Height South Alignment Option (DEL-6b)

Mitigation	Side of Track	Start Station	End Station	Wall Height	Wall Length
At-grade-level and elevated sound wall	East	280+00	Continues in West Seattle Junction	4 to 8 feet	2,600 feet
At-grade-level and elevated sound wall	West	293+00	301+00	4 to 6 feet	800 feet

Under Alternative DEL-1a, the following sound walls would be needed:

- A sound wall from the Duwamish Segment would continue along the east side of the elevated guideway to the curve on to Southwest Genesee Street, ending approximately 400 feet west of 26th Avenue Southwest. A shorter length would be needed when connecting to Alternative DUW-2 in the Duwamish Segment.
- Sound walls on the west side of the elevated structure along Southwest Delridge Way and along Southwest Genesee Street, continuing to the West Seattle Junction Segment.

Sound walls on the east side of the elevated guideway on Southwest Genesee Street east of Southwest Avalon Way, continuing to the West Seattle Junction Segment. Noise mitigation no less effective than a 4-foot sound wall would also be integral on both sides of the Delridge Station. Mitigation no less effective than a 4-foot wall means that the station design would include elements that would provide the same reduction as a wall that was at least 4 feet above the top or rail. Due to different installation techniques of the rails that are unknown at this time, the noise mitigation in some areas, for example stations, are specified using this terminology. All sound walls would have a height of 4 feet to 6 feet and with the proposed mitigation, all impacts under Alternative DEL-1a would be mitigated. The new walls also would provide noise mitigation for the FTA Category 1 Secret Studio Records/Studio 1208. Table 7-6 summarizes the sound walls for Alternative DEL-1a.

Noise mitigation under Option DEL-1b would be the same as described for Alternative DEL-1a and would also be effective at mitigation of all noise impacts.

Table 7-6. Summary of Sound Walls for the Dakota Street Station Alternative (DEL-1a)

Mitigation	Side of Track	Start Station	End Station	Wall Height	Wall Length
Elevated sound wall [a]	East	Continued from Duwamish Segment	295+00	4 feet	2,500 feet
Elevated sound wall	West	282+00	Continues in West Seattle Junction	4 to 6 feet	2,800 feet
Elevated sound wall	East	306+00	Continues in West Seattle Junction	4 feet	400 feet

[a] Sound wall would be shorter in length when connecting to Alternative DUW-2.

Noise mitigation under Option DEL-1b would be the nearly the same as described for Alternative DEL-1a with one change in sound wall height from 4 feet to 6 feet at the southwest corner of Southwest Avalon Way and Southwest Genesee Street before dropping back down to 4 feet at the Delridge and West Seattle Junction segments border. Table 7-7 summarizes the sound walls for Option DEL-1b.

Table 7-7. Summary of Sound Walls for the Dakota Street Station North Alignment Option (DEL-1b)

Mitigation	Side of Track	Start Station	End Station	Wall Height	Wall Length
Elevated sound wall	East	Continued from Duwamish Segment	294+00	4 feet	2,400 feet
Elevated sound wall	West	282+00	Continues in West Seattle Junction	4 to 6 feet	2,800 feet
Elevated sound wall	East	306+00	Continues in West Seattle Junction	4 to 6 feet	400 feet

Under Alternative DEL-2a, the location and lengths of sound walls for the west side of the guideway are the same as described under Alternative DEL-1a; however, because of the lower track alignment, many of the sound walls along Delridge Way Southwest and Southwest Genesee Street would be taller, ranging from 4 to 8 feet tall. Sound walls along the east side of the guideway would also be the same as with Alternative DEL-1a with slightly taller walls of 4 to 6 feet, continuing from the Duwamish Segment to Southwest Genesee Street, ending approximately 400 feet west of 26th Avenue Southwest. Noise mitigation no less effective than a 4-foot sound wall would also be integral on both sides of the Delridge Station. The new walls would also provide noise mitigation for the FTA Category 1 Secret Studio Records/Studio 1208. Table 7-7 summarizes the sound walls for Alternative DEL-2a.

Even with sound walls of up to 8 feet, the following seven units would not be mitigated:

- Four units at the multi-family building The Edge Apartments at 3014 Southwest Genesee Street
- Three units at 3120 Avalon Way

All noise impacts identified would be to the exterior of the units. The Edge Apartments was constructed in 1958, prior to many current building requirements, and has no outdoor uses, and therefore may be a candidate for sound insulation such as improved windows and fresh air exchange systems. The final building, 3120 Avalon Way, is a newer building (constructed in 2002) and therefore would have double-pane windows. The impacts that could not be mitigated are on the upper floor of this six-floor building. If this alternative is selected, additional testing may be performed at each of these buildings. The purpose of the testing would be to determine the interior noise levels from transit operations and to verify compliance that they meet the Department of Housing and Urban Development requirements or provide recommended acoustical improvements. However, with the sound walls and building insulation as needed, the interior noise levels would be within Department of Housing and Urban Development requirements, and all noise impacts would be mitigated. Table 7-8 summarizes the sound walls for Alternative DEL-2a.

Table 7-8. Summary of Sound Walls for the Dakota Street Station Lower Height Alternative (DEL-2a)

Mitigation	Side of Track	Start Station	End Station	Wall Height	Wall Length
Elevated sound wall	East	Continued from Duwamish Segment	293+00	4 feet	2,30 feet
Elevated sound wall	West	282+00	Tunnel Portal	4 to 8 feet	2,500 feet

Option DEL-2b would be to the north along Southwest Genesee Street and would remove several of the buildings near Southwest Avalon Way. The sound walls would be similar to Alternative DEL-2a, with wall heights ranging from 4 feet to 8 feet. Noise mitigation no less effective than a 4-foot sound wall would also be integral on both sides of the Delridge Station. The new walls also provide noise mitigation for the FTA Category 1 Secret Studio Records/Studio 1208. Under this alternative, there are approximately four top-floor (sixth-floor) units at the Youngstown Flats that could not be mitigated with walls. The impacts at the Youngstown Flats under Option DEL-2b are slightly different than Alternative DEL-2a because the elevation of the track and station location are slightly different. This slight change in the track elevation and station location increases the number of impacts remaining, even with an 8-foot sound wall. If this alternative is selected, additional testing may be performed at those units where noise mitigation was not predicted to resolve impacts. The purpose of the testing would be to determine the interior noise levels from transit operations and verify that they meet the Department of Housing and Urban Development requirements for residences. With the sound walls and building insulation as needed, the interior noise levels would be within Department of Housing and Urban Development requirements. Table 7-9 summarizes the sound walls for Option DEL-2b.

Table 7-9. Summary of Sound Walls for the Dakota Street Station Lower Height North Alignment Option (DEL-2b)

Mitigation	Side of Track	Start Station	End Station	Wall Height	Wall Length
Elevated sound wall	East	Continued from Duwamish Segment	294+00	4 feet	2,400 feet
Elevated sound wall	West	282+00	Tunnel Portal	4 to 8 feet	2,500 feet

Under Alternative DEL-3, the following sound walls would be needed:

- Sound walls on the east side of the guideway continuing from the Duwamish Segment to Southwest Genesee Street and ending approximately 100 feet west of 26th Avenue Southwest
- Sound walls on the west side of the guideway along Delridge Way Southwest south of Southwest Andover Street and ending along Southwest Genesee Street approximately 500 feet east of Delridge Way Southwest

- Sound walls on the west side of the structure from the north end of the Delridge Station to the connection in the West Seattle Junction Segment
- Sound walls on the east side of the elevated guideway along Southwest Genesee Street east of Southwest Avalon Way, continuing to the West Seattle Junction Segment

Noise mitigation no less effective than a 4-foot sound wall would also be integral along the east side of the Delridge Station. The new walls also provide noise mitigation for the FTA Category 1 Secret Studio Records/Studio 1208. With the new sound walls, all noise impacts are mitigated. Table 7-10 summarizes the sound walls for Alternative DEL-3.

Table 7-10. Summary of Sound Walls for the Delridge Way Station Alternative (DEL-3)

Mitigation	Side of Track	Start Station	End Station	Wall Height	Wall Length
Elevated sound wall	East	Continued from Duwamish Segment	291+00	4 to 6 feet	2,000 feet
Elevated sound wall	East	294+00	298+00	4 feet	400 feet
Elevated sound wall	East	306+00	309+00	4 feet	300 feet
Elevated sound wall	West	Delridge Station	Continues in West Settle Junction	4 to 6 feet	3,100 feet

Under Alternative DEL-4, the following sound walls would be needed:

- Sound walls on the east side of the guideway continuing from the Duwamish Segment to Southwest Genesee Street and ending approximately 100 feet west of 26th Avenue Southwest
- Sound walls on the west side of the structure from the north end of the Delridge Station to the connection in the West Seattle Junction Segment

Noise mitigation under Alternative DEL-4 would range from 4- to 8-foot-tall walls to account for the lower track elevations. Even with the walls, four units on the upper floor at the multi-family building at 3101 Southwest Avalon Way are predicted to meet or exceed the FTA criteria. Therefore, the upper-floor units in this multi-family building may be candidates for sound insulation. If this alternative is selected, additional testing may be performed. The purpose of the testing would be to determine the interior noise levels from transit operations and to verify that they meet the Department of Housing and Urban Development requirements for residences or to provide recommended structural improvements. However, with the sound walls and building insulation as needed, the interior noise levels would be within Department of Housing and Urban Development requirements, and all noise impacts would be mitigated. Table 7-11 summarizes the sound walls for Alternative DEL-4.

Table 7-11. Summary of Sound Walls for the Delridge Station Lower Height Alternative (DEL-4)

Mitigation	Side of Track	Start Station	End Station	Wall Height	Wall Length
At-grade-level and elevated sound wall	East	Continued from Duwamish Segment	297+00	4 to 6 feet	2,600 feet
At-grade-level and elevated sound wall	West	280+00	Tunnel Portal	4 to 8 feet	3,000 feet

For Alternative DEL-5, the following sound walls would be needed:

- The continuation of the 4-foot-tall sound wall on the east side of the guideway in the Duwamish Segment for an additional 300 feet, providing noise mitigation for residences along Southwest Delridge Way and 23rd Avenue Southwest
- A second, 4-foot-tall, east-side sound wall continuing from just east of 26th Avenue Southwest to just east of 28th Avenue, providing noise mitigation for the Youngstown Flats multi-family building

A third, 4-foot-tall, east-side sound wall with a parallel, 4- to 8-foot-tall, sound wall on the west side from just west of 28th Avenue Southwest to the connection to the West Seattle Junction Segment. There are up to 15 multi-family residences in a nine-floor building at 3050 Southwest Avalon Way that are well above the guideway and could not be mitigated with sound walls; however, this building was constructed in 2018, has no external uses at the upper floors, and given current construction requirements for double-pane windows and wall insulation, interior noise levels at these units are likely within Department of Housing and Urban Development requirements. If this alternative is selected, additional testing may be performed at those units where noise mitigation was not predicted to resolve impacts. The purpose of the testing would be to determine the interior noise levels from transit operations and to verify that they meet the Department of Housing and Urban Development requirements for residences or to provide recommended structural improvements. With the sound walls and building insulation as needed, the interior noise levels would be within Department of Housing and Urban Development requirements. Table 7-12 summarizes the sound walls for Alternative DEL-5.

Table 7-12. Summary of Sound Walls for the Andover Street Station Alternative (DEL-5)

Mitigation	Side of Track	Start Station	End Station	Wall Height	Wall Length
Elevated sound wall	East	273+00	276+00	4 feet	300
Elevated sound wall	East	279+00	282+00	4 feet	300 feet
Elevated sound wall	East	287+00	Continues in West Seattle Junction	4 feet	1,900 feet
Elevated sound wall	West	292+00	Continues in West Seattle Junction	4 to 8 feet	1,400

Noise mitigation for Alternative DEL-6a begins at the connection to the Duwamish Segment, with a continued sound wall just east of the Delridge Station. Alternative DEL-6a would also have a sound wall along the east side of the guideway for mitigation at the Youngstown Flats multi-family building. Sound walls would also be required along the east side of the guideway from just east of 28th Avenue Southwest, continuing to the tunnel portal to the West Seattle Junction Segment. Finally, a 6- to 8-foot-tall sound wall would be needed along the west side of the guideway for approximately 800 feet starting at Southwest Avalon Way. The sound walls are sufficient to mitigate all potential noise impacts under Alternative DEL-6a. Table 7-13 summarizes the sound walls for Alternative DEL-6a.

Table 7-13. Summary of Sound Walls for the Andover Street Station Lower Height Alternative (DEL-6a)

Mitigation	Side of Track	Start Station	End Station	Wall Height	Wall Length
Elevated sound wall	East	Continued from Duwamish Segment	274+00	4 feet	300 feet
Elevated sound wall	East	278+00	282+00	4 feet	400 feet
At-grade-level and elevated sound wall	East	292+00	Continues in West Seattle Junction	4 to 8 feet	1,400 feet
At-grade-level and elevated sound wall	West	292+00	300+00	4 to 8 feet	800 feet

Noise mitigation for Alternative DEL-7 begins south of the Delridge Station with 4- to 6-foot-tall sound walls along the east side of the guideway and continues to the tunnel portal. Noise mitigation would not be required at the Delridge Station as it would be further away from sensitive receivers east of Delridge Way Southwest. A 4-foot-tall sound wall would also be required along the westside of the guideway from the intersection of Southwest Avalon Way and Southwest Andover Street till just before the tunnel portal entrance.

Even with the walls, two units at the multi-family building at 3000 Southwest Avalon Way and two single-family residences at 4031 and 4035 32nd Avenue Southwest are predicted to meet or exceed the FTA criteria. Therefore, these residences may be candidates for sound insulation. If this alternative is selected, additional testing may be performed. The purpose of the testing would be to determine the interior noise levels from transit operations and to verify that they meet the Department of Housing and Urban Development requirements for residences or to provide recommended structural improvements. However, with the sound walls and building insulation as needed, the interior noise levels would be within Department of Housing and Urban Development requirements and all noise impacts would be mitigated. Table 7-14 summarizes the sound walls for Alternative DEL-7.

Table 7-14. Summary of Sound Walls for the Andover Street Station Lower Height No Avalon Station Tunnel Connection (DEL-7)

Mitigation	Side of Track	Start Station	End Station	Wall Height	Wall Length
Elevated sound wall	East	280+00	Tunnel Portal	4 to 6 feet	2,100 feet
Elevated sound wall	East	294+00	298+00	4 feet	400 feet

7.1.3.4 West Seattle Junction Segment

Sound walls are summarized by alternative in Tables 7-15 through 7-19. Project station numbering is provided in each of the tables as a reference for the wall locations.

Under Preferred Option WSJ-5b, the sound wall would continue from the Delridge Segment on the east side of the trackway. The 6- to 10-foot-tall sound walls just prior to Avalon Station would mitigate noise coming from the retained cut. Table 7-15 summarizes the new wall.

Table 7-15. Summary of Sound Walls for the Preferred Medium Tunnel 41st Avenue Station West Entrance Station Option (WSJ-5b)

Mitigation	Side of Track	Start Station	End Station	Wall Height	Wall Length
At-grade-level	East	Continued from Delridge Segment	309+00	6 to 10 feet	400 feet

Alternative WSJ-1 would continue sound walls on both sides of the guideway from the Delridge Segment, including at the Avalon Station. Sound walls up to 8 feet tall would be required for the upper floors of the multi-family units south of the station area. The walls on the east and south side of the guideway would continue to the west side of 35th Avenue Southwest, where land use changes to commercial and no mitigation is needed. On the west and north side of the guideway, the walls end at 35th Avenue Southwest and start again near 37th Avenue Southwest, continuing at 4 to 8 feet tall to the end of the alignment near Southwest Hudson Street. Sound walls would also be needed along the east and south of the guideway near Southwest Oregon Street, 40th Avenue Southwest and from Southwest Alaska Street to the end of the guideway.

Because of the severe noise impacts and building elevations, sound walls would not be sufficient to fully mitigate the noise impacts at the following locations:

- A single-family residence on 40th Avenue Southwest
- Upper-floor units at the multi-family building at 4100 Southwest Alaska Street
- Upper-floor units at the multi-family building at 5000 California Avenue Southwest

The noise impact at the single-family residence on 40th Avenue Southwest is due in part to the double crossover and requires special trackwork mitigation in addition to the sound wall. The remaining sites would be considered for sound insulation as needed, but the buildings at 4100 Southwest Alaska Street are newer construction and would be equipped with double-pane windows. The multi-family building at 5000 California Avenue Southwest was constructed in 1984 and had a major remodel performed in 2018 that may have included installation of improved windows. If this alternative is selected, additional testing may be performed at each of these buildings. The purpose of the testing would be to determine the interior noise levels from transit operations and to verify that they meet the Department of Housing and Urban Development requirements for residences or to provide recommended structural improvements. With the sound walls, special trackwork, and building insulation as needed, the interior noise levels would be within Department of Housing and Urban Development requirements, and all noise impacts would be mitigated. Table 7-16 summarizes the sound walls for Alternative WSJ-1.

Table 7-16. Summary of Sound Walls for the Elevated 41st/42nd Avenue Station Alternative (WSJ-1)

Mitigation	Side of Track	Start Station	End Station	Wall Height	Wall Length
Elevated sound wall	East	Continued from Delridge Segment	317+00	4 to 8 feet	800 feet
Elevated sound wall	West	Continued from Delridge Segment	312+00	4 feet	300
Elevated sound wall	West	319+00	Project Terminus	4 to 8 feet	3,600 feet
Elevated sound wall	East	329+00	333+00	4 feet	400 feet
Elevated sound wall	East	337+00	340+00	4 feet	300 feet
Elevated sound wall	East	343+00	Project Terminus	4 feet	1,200 feet

Alternative WSJ-2 would also continue the sound walls from the Delridge Segment on both sides of the alignment and include the same noise mitigation at the station. Sound walls would also be needed on the west side of the structure (north) near 36th Avenue Southwest to the Alaska Junction Station. Sound walls on the east side of the guideway (south) would resume south of Southwest Oregon Street to and including the Alaska Junction Station with mitigation equivalent to a 6-foot wall. North of the Alaska Junction Station, 4-foot sound walls would continue to mitigate sound from light rail operations on the trail tracks. Sound insulation would be considered for upper floors of a multi-family building on Fauntleroy Way Southwest (4800 and 4830) near the project terminus. The building was constructed in the 1980s and would be considered for sound insulation and tested to verify the interior noise levels from transit operations meet the Department of Housing and Urban Development requirements for residences if this alternative is selected. With the set of noise mitigation measures (i.e., walls and sound insulation), all noise impacts would be mitigated. Table 7-17 summarizes the walls proposed for Alternative WSJ-2.

Table 7-17. Summary of Sound Walls for the Elevated Fauntleroy Way Station Alternative (WSJ-2)

Mitigation	Side of Track	Start Station	End Station	Wall Height	Wall Length
Elevated sound wall [a]	East	Continued from Delridge Segment	317+00	4 to 6 feet	800 feet
Elevated sound wall	West	Continued from Delridge Segment	338+00	4 feet	2,900 feet
Elevated sound wall	East	331+00	Project Terminus	4 to 8 feet	1,300 feet
Elevated sound wall	West	342+00	Project Terminus	4 to 6 feet	200 feet

[a] Sound wall would be shorter in length when connecting to Option DEL-1b.

Under Alternative WSJ-3a and Option WSJ-3b, the alignment is entirely in a tunnel in the West Seattle Junction Segment and no noise impacts were identified and no mitigation is required.

Alternative WSJ-4 would continue the sound walls from the Delridge Station on both sides of the alignment and include noise mitigation at the Avalon Station. The 4- to 6-foot-tall walls would mitigate noise from the station. An additional 4-foot sound wall would be required along the west and north side of the guideway from near 36th Avenue Southwest to just prior to the tunnel portal. All impacts would be mitigated. Table 7-18 summarizes the new sound wall.

Table 7-18. Summary of Sound Walls for the Short Tunnel 41st Avenue Station (WSJ-4)

Mitigation	Side of Track	Start Station	End Station	Wall Height	Wall Length
Elevated sound wall	West	Continued from Delridge	316+00	4 feet	700 feet
Elevated sound wall	East	Continued from Delridge	316+00	4 to 6 feet	700 feet
Elevated sound wall	West	319+00	327+00	4 feet	800 feet

Alternative WSJ-5a would continue the sound walls from the Delridge Segment on the east side of the trackway. The 4- to 8-foot-tall sound walls just prior to Avalon Station would mitigate noise coming from the retained-cut segment. Table 7-19 summarizes the new wall.

Table 7-19. Summary of Sound Walls for the Medium Tunnel 41st Station Alternative (WSJ-5a)

Mitigation	Side of Track	Start Station	End Station	Wall Height	Wall Length
At-grade-level	East	Continued from Delridge Segment	309+00	4 to 8 feet	400 feet

Under Alternative WSJ-6, the alignment is entirely in a tunnel in the West Seattle Junction Segment and no noise impacts were identified. Therefore, no mitigation is required.

7.2 Construction Noise Mitigation

Construction activities will be required to comply with codified sound limits. Nighttime construction would require a noise variance from the City of Seattle. Noise mitigation would likely be required for construction activities to comply with Seattle Municipal Code or variance sound level limits. The contractor will develop a Noise Control Plan prior to construction. The Noise Control Plan will detail the construction equipment and methods that will be used throughout the project, predicted sound levels from various construction phases, noise monitoring and reporting requirements, and the types of noise mitigation that will be used to satisfy project sound level limits. These noise mitigation measures may include the following, as appropriate:

- Schedule construction activities to occur during daytime hours, or if nighttime construction is unavoidable, schedule the loudest construction activities for daytime hours.
- Install construction noise barriers between the construction site and noise-sensitive properties at tunnel portals, or other construction areas where nighttime construction or long periods of construction are anticipated.
- Use backup warning devices that are the least intrusive broadband type on all equipment or use backup observers as permitted by law.
- Use low-noise emission equipment.
- Use bed lining such as soil, gravel, or rubber in all haul truck beds.
- Monitor and maintain equipment to meet noise limits.
- Use lined or covered storage bins, conveyors, and chutes with sound-deadening material.
- Use radios for all long-range communication onsite; no yelling should be permitted except in case of an emergency.
- Limit use of public address systems.
- Remove any material or debris spilled on pavement by hand sweeping and avoid scraping type equipment or activity will be used to clean pavement surfaces.
- Limit engine idling to not more than two minutes when vehicles or equipment are not directly engaged in work activity.
- Locate stationary equipment away from noise-sensitive properties to the extent possible.
- Where practical, minimize the use of generators or use generators in sound-rated enclosures.
- Operate equipment to minimize banging, clattering, buzzing, and other annoying types of noises.

- To the extent feasible, configure the construction site in a manner that keeps noisier equipment and activities as far as practicable from noise-sensitive locations and nearby buildings.
- Provide enclosures for stationary equipment and barriers around particularly noisy areas of the site.
- Phase start-up of equipment and avoid simultaneous high-noise activities.
- Fit equipment with high-grade engine exhaust silencers and/or engine shrouds.
- Additional coordination of the construction activities and scheduling may also be necessary with sensitive land uses along the corridor, including recording studios, performance arts centers, and other highly sensitive land uses.

7.3 Operational Vibration Mitigation

7.3.1 Vibration Mitigation Approaches

Several different approaches have been used by rail transit systems to reduce groundborne vibration and groundborne noise. The most common vibration mitigation measures used on light rail systems consist of placing a resilient layer between the track and the soil. Some standard approaches for vibration mitigation measures with direct-fixation track are as follows:

- High-resilience fasteners: Direct-fixation track fasteners are used to attach the rail to the concrete track slab in a tunnel or on an elevated structure. High-resilience fasteners include a soft, high-resilience element (nominal vertical static stiffness of 60,000 pounds force inch and a dynamic to static ratio of 1.4:1) to provide greater vibration isolation than standard rail fasteners in the vertical direction.
- Floating slabs: Floating slab consists of a concrete slab supported by elastomer springs on a concrete foundation. The elastomer springs could be a continuous mat or individual springs. The frequency range at which a floating slab is effective depends on the thickness of the slab and the stiffness of the springs. Floating slabs are very effective at reducing vibration levels, particularly at low frequencies. However, they are also very expensive.
- Low-impact special trackwork: The impacts of vehicle wheels over rail gaps at special trackwork locations such as turnouts and switches can increase vibration levels by up to 10 dB. If special trackwork cannot be located away from vibration-sensitive receivers, another approach is to use low-impact frogs. Spring-rail and moveable-point frogs allow the flangeway gap to remain closed in the main traffic direction for revenue service trains and can almost completely reduce the vibration increase caused by special trackwork. Monoblock frogs are milled out of a single block of steel and their tolerances can be tighter than a traditional frog, which reduces the vibration increase. Flange-bearing frogs include a ramp to support the flange of the wheel to minimize banging. Well-designed monoblock and flange-bearing frogs can reduce the vibration level increase by about half compared to a standard frog.
- Alternative approaches: There are alternative vibration mitigation approaches that may be applied under specific circumstances. Examples include increasing the thickness of the concrete under the track, specifying straighter rails, and building the track on top of pile foundation systems when the track would traverse very soft sections of soil.

The typical vibration mitigation measure for ballast-and-tie track is ballast mat; however, there would be no vibration exceedances in ballast-and-tie track areas.

7.3.2 Proposed Operational Vibration Mitigation

Vibration mitigation is proposed for all sensitive receivers where there would be impacts. Locations of vibration impacts are shown in the maps in Attachment N.3E. The key points of mitigation are as follows:

- High-resilience fasteners are proposed for most vibration and groundborne noise exceedances for direct-fixation track for tunnels or elevated structure.
- Low-impact frogs are proposed at locations where exceedances are predicted as a result of amplification from special trackwork. Moveable-point frogs and monoblock frogs are examples of low-impact frogs that provide different levels of vibration reduction. Moveable-point frogs are proposed as a low-impact frog where the projected levels exceed the limit by more than 5 dB. Monoblock frogs are proposed as a low-impact frog where the projected levels exceed the limit by less than 5 dB. Low-impact frogs with similar performance could be used in place of the proposed frog.

During final design, the vibration analysis will be refined before finalizing mitigation measures. Increasing the distance between the track and the closest sensitive receiver by removing buildings may eliminate the need for track-based mitigation. Site-specific vibration measurements at locations where vibration exceedances are predicted could also be used to refine the predicted vibration levels and mitigation recommendations.

The following sections describe the mitigation recommendations for each segment of the West Seattle Link Extension. High-resilience fasteners are used to connect the rail to the track slab and are softer than traditional fasteners, which allows them to absorb some of the vibration that is transmitted from the rail into the ground. The lifespan is similar to traditional fasteners, and no special maintenance is required. A frog is a component of special trackwork where there is a gap in the rail to allow one rail to cross another. The impacts of vehicle wheels over rail gaps can cause high levels of noise and vibration. Low-impact frogs are designed to reduce the impact forces at the gap, and as a result produce lower noise and vibration levels.

7.3.2.1 SODO Segment

There would be no vibration impacts for any alternatives in the SODO Segment; therefore, no vibration mitigation measures are proposed.

7.3.2.2 Duwamish Segment

There would be no vibration impacts for Option DUW-1b and Alternative DUW-2. Impacts for Preferred Alternative DUW-1a are projected in two different special trackwork areas: at Fire Station 14 in east Duwamish near the turnout at the entrance to the Maintenance Facility and at a single-family residence near the crossover east of Delridge Way Southwest near the West Seattle Bridge on-ramp. Proposed mitigation at both locations would be a low-impact frog, such as a monoblock frog. At both locations, the predicted vibration level exceeds the impact threshold by less than 1 decibel. Additional analysis or refinement of the prediction model during final design may show that the predicted levels are below the impact threshold without mitigation.

Table 7-20 summarizes the proposed mitigation measures for the Preferred Alternative DUW-1a vibration impacts.

Table 7-20. Summary of Vibration and Groundborne Noise Impacts and Proposed Mitigation for the Preferred South Crossing Alternative (DUW-1a)

Alternatives and Design Options	Sound Transit Right-of-way I.D.	Number of Impacts	Proposed Mitigation	Start Station	End Station	Approximate Length of Mitigation (feet)
DUW-1a	WS10046	1	Reassessment (exceeds by less than 1 dB)/ Low-impact frog, monoblock	SB-W 174+00	SB-W 174+00	Not applicable
DUW-1a (*when connecting to DEL-6b only*)	WS5541	1	Reassessment (exceeds by less than 1 dB)/ Low-impact frog, monoblock	SB-W 266+00	SB-W 266+00	Not applicable

7.3.2.3 Delridge Segment

There would be no vibration impacts for Option DEL-1b, Alternative DEL-2a, Option DEL-2b, and Alternative DEL-4. Impacts and proposed mitigation for the other alternatives would be as follows:

- Preferred Option DEL-6b would have a vibration impact at one single-family residence located close to the elevated structure near the intersection of Southwest Andover Street and Southwest Avalon Way. The proposed mitigation is high-resilience fasteners.
- Alternative DEL-1a would have a vibration impact at a multi-family residential building near the curve at the intersection of Southwest Genesee Street and Southwest Avalon Way. The proposed mitigation is high-resilience fasteners.
- Alternative DEL-3 would have a vibration impact at one multi-family building near the curve at the intersection of Southwest Genesee Street and Southwest Avalon Way. The proposed mitigation measure is high-resilience fasteners.
- Alternative DEL-5 would have vibration impacts at the multi-family building at the intersection of Southwest Dakota Street and 30th Avenue Southwest. The proposed mitigation measure is high-resilience fasteners.
- For Alternative DEL-6a, there would be vibration impacts at the buildings near the intersection of Yancy Street and 32nd Avenue Southwest and at a building near the retained-cut portion of the alignment on 32nd Avenue Southwest. The proposed mitigation measure is high-resilience fasteners.
- For Alternative DEL-7, there would be groundborne noise impacts at the residences where the tunnel gets shallower as it approaches the tunnel portal. The proposed mitigation is high-resilience fasteners.

Table 7-21 through Table 7-26 summarize the proposed mitigation measures for the Delridge Segment Build Alternatives with vibration impacts.

Table 7-21. Summary of Vibration and Groundborne Noise Impacts and Proposed Mitigation for the Preferred Andover Street Station Lower Height South Alignment Option (DEL-6b)

Alternatives and Design Options	Sound Transit Right-of-way I.D.	Number of Impacts	Proposed Mitigation	Start Station	End Station	Approximate Length of Mitigation (feet)
DEL-6b	WS7185	1	Reassessment (exceeds by less than 1 dB)/ High- resilience direct-fixation fasteners	SB-W 293+00	SB-W 297+00	400

Table 7-22. Summary of Vibration and Groundborne Noise Impacts and Proposed Mitigation for the Dakota Street Station Alternative (DEL-1a)

Alternatives and Design Options	Sound Transit Right-of-way I.D.	Number of Impacts	Proposed Mitigation	Start Station	End Station	Approximate Length of Mitigation (feet)
DEL-1a	WS1094	12	Reassessment (exceeds by less than 1 dB)/ High- resilience direct-fixation fasteners	SB-W 305+00	SB-W 309+00	400

Table 7-23. Summary of Vibration and Groundborne Noise Impacts and Proposed Mitigation for the Delridge Way Station Alternative (DEL-3)

Alternatives and Design Options	Sound Transit Right-of-way I.D.	Number of Impacts	Proposed Mitigation	Start Station	End Station	Approximate Length of Mitigation (feet)
DEL-3	WS1094	12	Reassessment (exceeds by less than 1 dB)/High-resilience direct-fixation fasteners	SB-W 305+00	SB-W 309+00	400

Table 7-24. Summary of Vibration and Groundborne Noise Impacts and Proposed Mitigation for the Andover Street Station Alternative (DEL-5)

Alternatives and Design Options	Sound Transit Right-of-way I.D.	Number of Impacts	Proposed Mitigation	Start Station	End Station	Approximate Length of Mitigation (feet)
DEL-5	WS82100	9	High-resilience direct-fixation fasteners	SB-W 294+00	SB-W 298+00	400

Table 7-25. Summary of Vibration and Groundborne Noise Impacts and Proposed Mitigation for the Andover Street Station Lower Height Alternative (DEL-6a)

Alternative	Sound Transit Right-of-way I.D.	Number of Impacts	Proposed Mitigation	Start Station	End Station	Approximate Length of Mitigation (feet)
DEL-6a	WS7154, WS7120, WS7117	3	High-resilience direct-fixation fasteners	SB-W 294+00	SB-W 305+00	1,100

Table 7-26. Summary of Vibration and Groundborne Noise Impacts and Proposed Mitigation for the Andover Street Station Lower Height No Avalon Station Tunnel Connection Alternative (DEL-7)

Alternatives and Design Options	Sound Transit Right-of-way I.D.	Number of Impacts	Proposed Mitigation	Start Station	End Station	Approximate Length of Mitigation (feet)
DEL-7	WS7151, WS7215, WS7350, WS7351, WS7352, WS7335, WS7336, WS7391, WS7214	9	High-resilience direct-fixation fasteners	SB-W 297+00	SB-W 306+00	900

7.3.2.4 West Seattle Junction Segment

There would be no vibration impacts for Alternative WSJ-2. Impacts and proposed mitigation for the remaining West Seattle Junction Segment Build Alternatives would be as follows:

- For Preferred Option WSJ-5b, there would be groundborne noise impacts where the tunnel is shallowest near the tunnel portal and along the curve. The proposed mitigation at both of these locations is high-resilience fasteners. There would also be groundborne noise impact near the special trackwork south of the Alaska Junction Station. The proposed mitigation is a low-impact frog, such as a moveable-point frog. Site-specific vibration propagation data may show that a monoblock or flange-bearing frog provides sufficient mitigation.
- For Alternative WSJ-1, there would be groundborne noise impacts at parcels close to a crossover. The proposed mitigation is a low-impact frog, such as a monoblock frog.
- For Alternative WSJ-3a, there would be groundborne noise impacts at residences east of the Avalon Station where the tunnel would be shallower and at residences near the curve between Southwest Oregon Street and Southwest Alaska Street. The proposed mitigation measure in this area is high-resilience fasteners. Site-specific vibration propagation data at residences near Avalon Station may show that mitigation is not necessary, because most of the projected levels exceed the criteria by less than 2 dB, which is less than the safety factor applied in the prediction model. There would also be a groundborne noise impact near the special trackwork south of the Alaska Junction Station. The proposed mitigation is a low-

impact frog, such as a moveable-point frog. Site-specific vibration propagation data may show that a monoblock or flange-bearing frog provides sufficient mitigation.

- The proposed mitigation for Option WSJ-3b is similar to the recommendations for Alternative WSJ-3a. Groundborne noise impacts would occur at residences east of Avalon Station where the tunnel would be shallower. The proposed mitigation measure in this area is high-resilience fasteners. There would also be groundborne noise impacts at residences on 42nd Avenue Southwest near the crossover south of the Alaska Junction Station. The proposed mitigation is a low-impact frog, such as a moveable-point frog. The projected groundborne noise levels at two of the buildings exceed the threshold for impact by more than 10 dB, which is the expected reduction of the low-impact frog. Site-specific vibration propagation testing is proposed to verify additional mitigation measures, such as high-resilience fasteners, are not necessary.
- For Alternative WSJ-4, there would also be groundborne noise impacts near the crossover south of the Alaska Junction Station and at the receivers north of the same station where the tunnel depth is shallower. The proposed mitigation for the special trackwork is a low-impact frog, such as a moveable-point frog. The proposed mitigation for the other groundborne noise impacts is high-resilience fasteners.
- For Alternative WSJ-5a, there would be groundborne noise impacts near the crossover south of the Alaska Junction Station and at the receivers between the Alaska Junction Station and Avalon Station where the tunnel would be shallower compared to some of the other alternatives. The proposed mitigation for the special trackwork is a low-impact frog, such as a moveable-point frog or spring-rail frog. The proposed mitigation for the other impacts is high-resilience fasteners.
- For Alternative WSJ-6, there would be groundborne noise impacts along the curve where the tunnel is shallower. The proposed mitigation is high-resilience fasteners. There would also be groundborne noise impact near the special trackwork south of the Alaska Junction Station. The proposed mitigation is a low-impact frog, such as a moveable-point frog.

Tables 7-27 through 7-33 summarize, by alternative, the proposed mitigation measures for the West Seattle Junction Segment.

Table 7-27. Summary of Vibration and Groundborne Noise Impacts and Proposed Mitigation for the Preferred Medium Tunnel 41st Avenue Station West Entrance Station Option (WSJ-5b)

Alternatives and Design Options	Sound Transit Right-of-way I.D.	Number of Impacts	Proposed Mitigation	Start Station	End Station	Approximate Length of Mitigation (feet)
WSJ-5b	WS6586, WS6585, WS6581, WS6580	4	High-resilience direct-fixation fasteners	SB-W 317+00	SB-W 323+00	600
WSJ-5b	WS6541, WS6540, WS6537, WS6536, WS2330, WS2332, WS3004, WS3002, WS6385, WS6384, WS2254, WS7584, WS7585, WS7583, WS7582, WS2280, WS2282, WS2284, WS2286, WS2288, WS2290, WS2292, WS2294, WS2264, WS2266, WS2268, WS2270	30	High-resilience direct-fixation fasteners	SB-W 326+00	SB-W 338+00	1,200
WSJ-5b	WS6114, WS2212, WS2210, WS2208, WS2206, WS2204, WS60300, WS2238	124	Low-impact frog, moveable-point	SB-W 342+00	SB-W 347+00	Not applicable

Table 7-28. Summary of Vibration and Groundborne Noise Impacts and Proposed Mitigation for the Elevated 41st/42nd Avenue Station Alternative (WSJ-1)

Alternatives and Design Options	Sound Transit Right-of-way I.D.	Number of Impacts	Proposed Mitigation	Start Station	End Station	Approximate Length of Mitigation (feet)
WSJ-1	WS5114, WS5115, WS6391, WS6390, WS6387	7	Low-impact frog, monoblock	SB-W 336+00	SB-W 336+00	Not applicable

Table 7-29. Summary of Vibration and Groundborne Noise Impacts and Proposed Mitigation for the Tunnel 41st Avenue Station Alternative (WSJ-3a)

Alternatives and Design Options	Sound Transit Right-of-way I.D.	Number of Impacts	Proposed Mitigation	Start Station	End Station	Approximate Length of Mitigation (feet)
WSJ-3a (*when connecting to DEL-2a only*)	WS5167, WS61000, WS60900, WS2422, WS2420, WS2418, WS2416, WS60800	161 [a]	High-resilience direct-fixation fasteners	SB-W 306+00	SB-W 315+00	900
WSJ-3a (*when connecting to DEL-2a only*)	WS7584, WS7585, WS2280, WS2282, WS2284, WS2286, WS2288, WS2290, WS2292, WS2294, WS2264, WS2266, WS2268, WS2270	14	High-resilience direct-fixation fasteners	SB-W 336+00	SB-W 343+00	700
WSJ-3a	WS1010, WS2204, WS2212, WS2210, WS2208, WS2206	24	Low-impact frog, moveable-point	SB-W 350+00	SB-W 350+00	Not applicable

[a] Alternative WSJ-3a with connection to Alternative DEL-2a would have impacts at the same 24 units as the original Alternative WSJ-3a, with 175 additional units for a total of 199 impacted units.

Table 7-30. Summary of Vibration and Groundborne Noise Impacts and Proposed Mitigation for the Tunnel 42nd Avenue Station Option (WSJ-3b)

Alternatives and Design Options	Sound Transit Right-of-way I.D.	Number of Impacts	Proposed Mitigation	Start Station	End Station	Approximate Length of Mitigation (feet)
WSJ-3b (*when connecting to DEL-2a only*)	WS5167, WS61000, WS60900, WS2422, WS2420, WS2418, WS2416, WS60800	161	High-resilience direct-fixation fasteners	SB-W 306+00	SB-W 315+00	900
WSJ-3b	WS2158, WS1006	269	Low-impact frog, moveable-point	SB-W 354+00	SB-W 354+00	Not applicable

Table 7-31. Summary of Vibration and Groundborne Noise Impacts and Proposed Mitigation for the Short Tunnel 41st Avenue Station Alternative (WSJ-4)

Alternatives and Design Options	Sound Transit Right-of-way I.D.	Number of Impacts	Proposed Mitigation	Start Station	End Station	Approximate Length of Mitigation (feet)
WSJ-4	WS6555, WS6554, WS6545, WS5122, WS5123, WS5125, WS5126, WS5130, WS5131, WS5132, WS5133, WS5127, WS5124, WS6395, WS6394, WS6391, WS6383, WS6382, WS6381, WS6380, WS6390, WS6392, WS6393, WS6377, WS6376, WS6375, WS6372, WS2260, WS2262, WS2272, WS2264, WS2266, WS2268, WS2270, WS7582, WS2274, WS2276, WS2278, WS6374, WS6391, WS5116, WS51000	124	High-resilience direct-fixation fasteners	SB-W 329+00	SB-W 343+00	1400
WSJ-4	WS1010, WS2218, WS2220, WS2222, WS2224, WS2226, WS2228, WS2232, WS2234, WS6115	29	Low-impact frog Moveable-point	SB-W 349+00	SB-W 349+00	Not applicable

Table 7-32. Summary of Vibration and Groundborne Noise Impacts and Proposed Mitigation for the Medium Tunnel 41st Avenue Station Alternative (WSJ-5a)

Alternatives and Design Options	Sound Transit Right-of-way I.D.	Number of Impacts	Proposed Mitigation	Start Station	End Station	Approximate Length of Mitigation (feet)
WSJ-5a	WS6586, WS6585, WS6581, WS6580	4	High-resilience direct-fixation fasteners	SB-W 317+00	SB-W 323+00	600
WSJ-5a	WS6541, WS6540, WS6537, WS6536, WS2330, WS2332, WS3004, WS3002, WS6385, WS6384, WS2280, WS7582, WS7583, WS7584, WS7585, WS2282, WS2284, WS2286, WS2288, WS2290, WS2292, WS2294, WS2264, WS2266, WS2268, WS2270, WS2254	29	High-resilience direct-fixation fasteners	326+00	338+00	1,200
WSJ-5a	WS1010, WS2204, WS6114, WS2212, WS2210, WS2208, WS2206	46	Low-impact frog, moveable-point	SB-W 342+00	SB-W 347+00	Not applicable

Table 7-33. Summary of Vibration and Groundborne Noise Impacts and Proposed Mitigation for the No Avalon Station Tunnel Alternative (WSJ-6)

Alternatives and Design Options	Sound Transit Right-of-way I.D.	Number of Impacts	Proposed Mitigation	Start Station	End Station	Approximate Length of Mitigation (feet)
WSJ-6	WS6526, WS2320, WS2318, WS2254, WS2262, WS2280, WS7584, WS7585, WS2282, WS2284, WS2286, WS2288, WS2290, WS2292, WS2294, WS2264, WS2266, WS2268, WS2270, WS2246, WS2248, WS2250	71	High-resilience direct-fixation fasteners	SB-W 331+00	SB-W 340+00	900
WSJ-6	WS1010, WS2204, WS6114, WS2212, WS2210, WS2208, WS2206, WS60300	73	Low-impact frog, moveable-point	SB-W 342+00	SB-W 347+00	Not applicable

7.4 Construction Vibration Mitigation

The primary means of mitigating vibration from construction activities is to require the contractor to prepare a detailed Construction Vibration Control Plan. The contractor will prepare the plan in conjunction with the contractor's specific equipment and methods of construction. Key elements of a plan are as follows:

- Contractor's specific equipment types.
- Schedule and methods of construction.
- Identification of all Category 1 and special-use buildings near construction sites.
- Methods for projecting construction vibration levels.
- Construction vibration limits.
- Specific vibration-control measures where predicted levels exceed the limits.
- Methods for responding to community complaints.

7.4.1 Potential Surface Construction Vibration Mitigation

Construction should be carried out in compliance with Sound Transit specifications and all applicable local regulations. Specific construction vibration mitigation measures should be developed during the design phase when more detailed construction means and methods information is available. The following mitigation measures should be applied as needed to minimize construction vibration impacts:

- **Pre-construction survey:** Prior to the start of construction, a survey of buildings including inspection and photographs of building foundations should be completed near construction areas. All potentially fragile structures within 200 feet should be included.
- **Construction timing:** Nighttime construction in residential neighborhoods should be avoided and businesses coordinated with to avoid interfering with sensitive daytime activities. Additional coordination of the construction activities and scheduling may also be necessary with sensitive land uses along the corridor, including recording studios, performance arts centers, and other highly sensitive land uses. Local ordinances should be followed unless variances are obtained.
- **Equipment location:** Stationary construction equipment should be as far as possible from vibration-sensitive sites.
- **Continuous vibration monitoring:** Monitoring can be implemented at particularly sensitive receivers, such as Category 1 or special-use buildings with low vibration limits.
- **Alternative construction methods:** Alternative construction methods should be used, where practical, to minimize the use of impact and vibratory equipment (e.g., pile drivers and compactors).

Predicted vibration levels from impact pile-driving exceed the impact threshold for potential risk of minor cosmetic building damage at structures within 100 feet. If pile-driving is planned within 100 feet of structures, alternative methods of pile installation or vibration monitoring would be considered. Examples of alternative construction methods for impact pile-driving are drilled shaft foundations or shallow spread footings. Pre-construction surveys would be conducted to document the existing conditions of buildings, and the contractor would be responsible for repairing damage due to the project. During final design, all impacts and proposed mitigation measures would be reviewed for verification.

The contractor, when selected, will prepare and implement a detailed Construction Vibration Control Plan that provides more detail on the construction vibration mitigation measures.

7.4.2 Potential Tunneling Vibration Mitigation

As discussed in Section 6.4.1, the predicted vibration levels generated by the tunnel boring machine are less than the impact thresholds. However, there may be exceedances of the groundborne noise threshold at Category 2 (residential) sensitive receivers from the tunnel boring machine cutterhead. The following presents options for reducing vibration from tunneling activities.

Tunnel boring machine cutterhead vibration is inherent to the operation of the machine, and the range of vibration experienced at sensitive receivers is largely dependent on the soil conditions at the cutterhead. Unfortunately, no mitigation measures exist to reduce tunnel boring machine cutterhead vibration levels, but vibration from the cutterhead would be temporary as the tunnel boring machine advances past the sensitive land uses (roughly 6 days for each bore as discussed in Section 6.4.1). Vibration monitoring and coordination with Category 1 and special-use buildings while the tunnel boring machine is passing can be used to minimize interruption of operations.

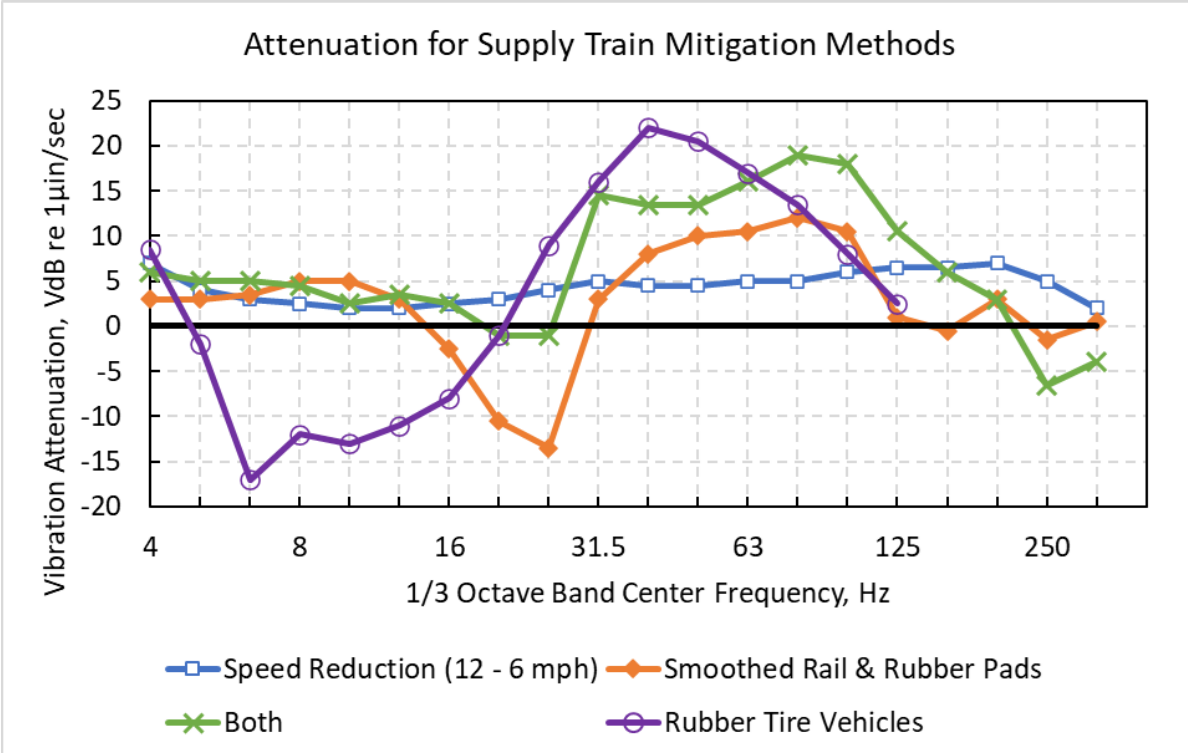
The vibration caused by the thrust jack retraction is not predicted to create damage or annoyance impacts and no mitigation is required. If complaints were to occur, they could be addressed by modifying the thrust jacks so that the cylinders are retracted slowly and eliminate the hard stop.

Operations of the supply train are not predicted to exceed the damage or annoyance impact threshold; however, the following options could mitigate vibration levels from the supply train if needed:

- Reducing the operating speed. Reducing the speed of the train from 12 miles per hour to 6 miles per hour provides a reduction in 1/3-octave band vibration levels from 2 to 7 VdB.
- Smoothing the running surface.
- Reducing the size of gaps between rail sections.
- Adding a rubber pad between the ties and the tunnel invert can also help reduce vibration levels from the supply train.
- Using rubber tire supply train vehicles, which generally reduce vibration to levels below the existing ambient, particularly at frequencies above 10 hertz.

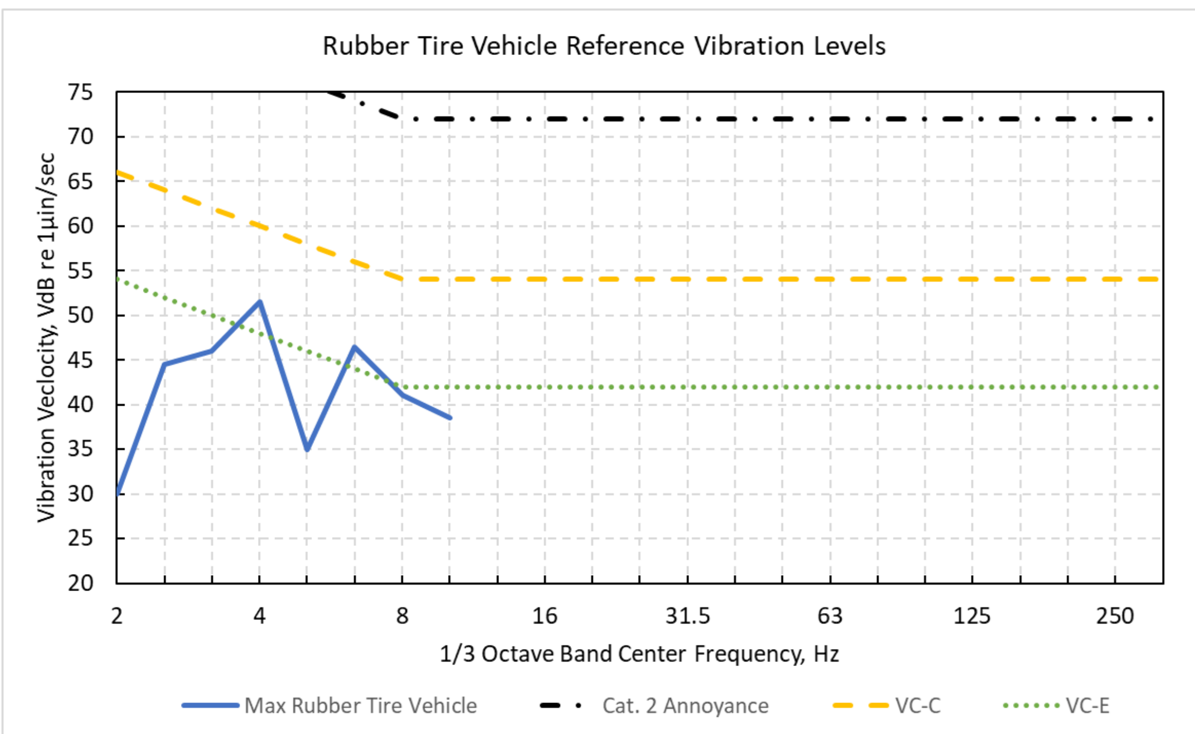
A comparison of the vibration attenuation provided by these supply train mitigation methods is provided on Figure 7-1. The attenuation provided by the rubber-tire-vehicle above 10 hertz is estimated assuming vibration levels of 35 VdB, because the measured data above 10 hertz were below the ambient level. Figure 7-2 shows the maximum vibration levels measured from the rubber tire vehicles that were used during boring of the University Link Extension tunnel. No data are available above 10 hertz, suggesting that the measured levels were at or below the existing ambient vibration at higher frequencies. As shown on Figure 7-2, vibration levels from rubber tire vehicles are well below the Category 2 threshold and are below the V.C.-E threshold (very demanding vibration criterion for extremely vibration-sensitive equipment) at most frequencies. Only Category 1 receivers that are highly sensitive to low-frequency vibration have the potential to be impacted by the operation of rubber tire vehicles during tunneling. Finally, in some locations, additional coordination of the construction activities and scheduling may be necessary to minimize impacts at sensitive land uses along the corridor.

Figure 7-1. Attenuation Levels Provided by Supply Train Mitigation Methods



Source: Bergen et al. 2012.

Figure 7-2. Reference Vibration Levels for Rubber Tire Supply Vehicles



Source: Bergen et al. 2012.

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