Washington State Department of Transportation

SR 520 Bridge Replacement and HOV Program

I-5 to Medina: Bridge Replacement and HOV Project

Final Construction Noise and Vibration Report
SR 520, West Connection Bridge Project

Prepared for

Washington State Department of Transportation

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Acronyms

ANSI	American National Standards Institute
APE	Area of potential effect
dB	logarithmic scale, known as the decibel scale
dBA	decibel measured on the A-weighted scale
CCMP	Community Construction Management Plan
Caltrans	California Department of Transportation
FTA	Federal Transit Administration
in/sec	inches per second
ISO	International Standards Organization
Lmax	maximum noise level
Leq	equivalent sound level
Lv	vibration velocity level
NTP	notice to proceed
PPV	peak particle velocity
RCNM	Roadway Construction Noise Model
SDEIS	Supplemental Draft Environmental Impact Statement
SR	State Route
VdB	RMS vibration velocity
WSDOT	Washington State Department of Transportation

Glossary

Crest factor: The ratio of peak particle velocity to maximum RMS amplitude in an oscillating signal.

Decibel (dB): The standard unit of measurement for sound pressure level and vibration level. Technically, a decibel is the unit of level which denotes the ratio between two quantities that are proportional to power; the number of decibels is 10 times the logarithm of this ratio. Also written as dB or dBA when measured on the A-weighted scale.

Equivalent Sound Level (Leq): Environmental sound fluctuates constantly. The equivalent sound level (Leq), sometimes referred to as the energy-average sound level, is the most common means of characterizing community noise. Leq represents a constant sound that, over the specified period, has the same sound energy as the time-varying sound.

One-third octave band: A standardized division of a frequency spectrum in which the octave bands are divided into thirds for more detailed information. The interval between center frequencies is a ratio of 1.25.

Peak Particle Velocity (PPV): The peak signal value of an oscillating vibration velocity waveform expressed in inches/second.

Receiver: A stationary far-field position at which noise or vibration levels are specified.

Root Mean Square (rms): The square root of the mean-square value of an oscillating waveform, where the mean-square value is obtained by squaring the value of amplitudes at each instant of time and then averaging these values over the sample time.

RMS Velocity Level (L_V): See "Vibration Velocity Level."

VdB: see Vibration Velocity Level.

Vibration Velocity Level (L_V): Ten times the common logarithm of the ratio of the square of the amplitude of the RMS vibration velocity to the square of the amplitude of the reference RMS vibration velocity. The reference velocity in the United States is one micro-inch per second also written as VdB.

Vibration: An oscillation wherein the quantity is a parameter that defines the motion of a mechanical system.

1 *Introduction*

This Construction Noise and Vibration Report (the Report) presents an assessment of the effects during construction of the SR 520, West Connection Bridge Project (the Project) on the historic and non-historic properties within the study area. The Report was prepared to meet the requirements of the Project Section 106 Programmatic Agreement which requires the Washington State Department of Transportation (WSDOT) to evaluate and to identify areas where impacts to historic properties within the area of potential effects (APE) may occur as a result of construction vibration. The Report also includes an assessment of the construction noise on the residential receivers within the study area. This is intended to inform the nearby residents of the expected noise levels during construction and compare these levels to the City of Seattle noise limits for these activities. The Report is based on the description of construction activities in the West Connection Bridge Work Platforms and Piling Technical Memorandum, June 2012.

The Report supplements the SR 520, I-5 to Medina: Bridge Replacement and HOV Project's 2009 Noise Discipline Report and its 2011 Addenda which is the previous assessment of the noise and vibration effects of the proposed construction for the SR 520, I-5 to Medina Bridge Replacement and HOV Project on the historic and non-historic properties during the construction. The Report also provides guidance and additional information on the noise and vibration generated during construction based on the planned means and methods of construction, the limits of the Seattle Noise Ordinance, and the locations for vibration monitoring during construction. The Report will become part of the Community Construction Management Plan (CCMP) for this Project.

The Report includes the following elements:

- Expected construction activities and equipment
- Locations of properties potentially affected by construction noise and vibration
    - Canterbury Shores and Edgewater Condominiums
- Construction noise criteria
- Vibration damage risk criteria
- Predicted worst-case construction noise and vibration levels
    - Impact pile driving and north side bridge rail demolition (from Pier 25 to Pier 30)
- Recommended construction mitigation measures
    - General noise and vibration control measures
    - Outreach to property owners
- Recommended construction vibration monitoring locations and criteria

Appendix A includes background information on the fundamentals of noise and vibration.

2 *Construction Activities*

This section contains brief descriptions of the expected major noise- and vibration-generating construction activities required for the different areas of the Project and the assumed construction means and methods that would be used by the Contractor.

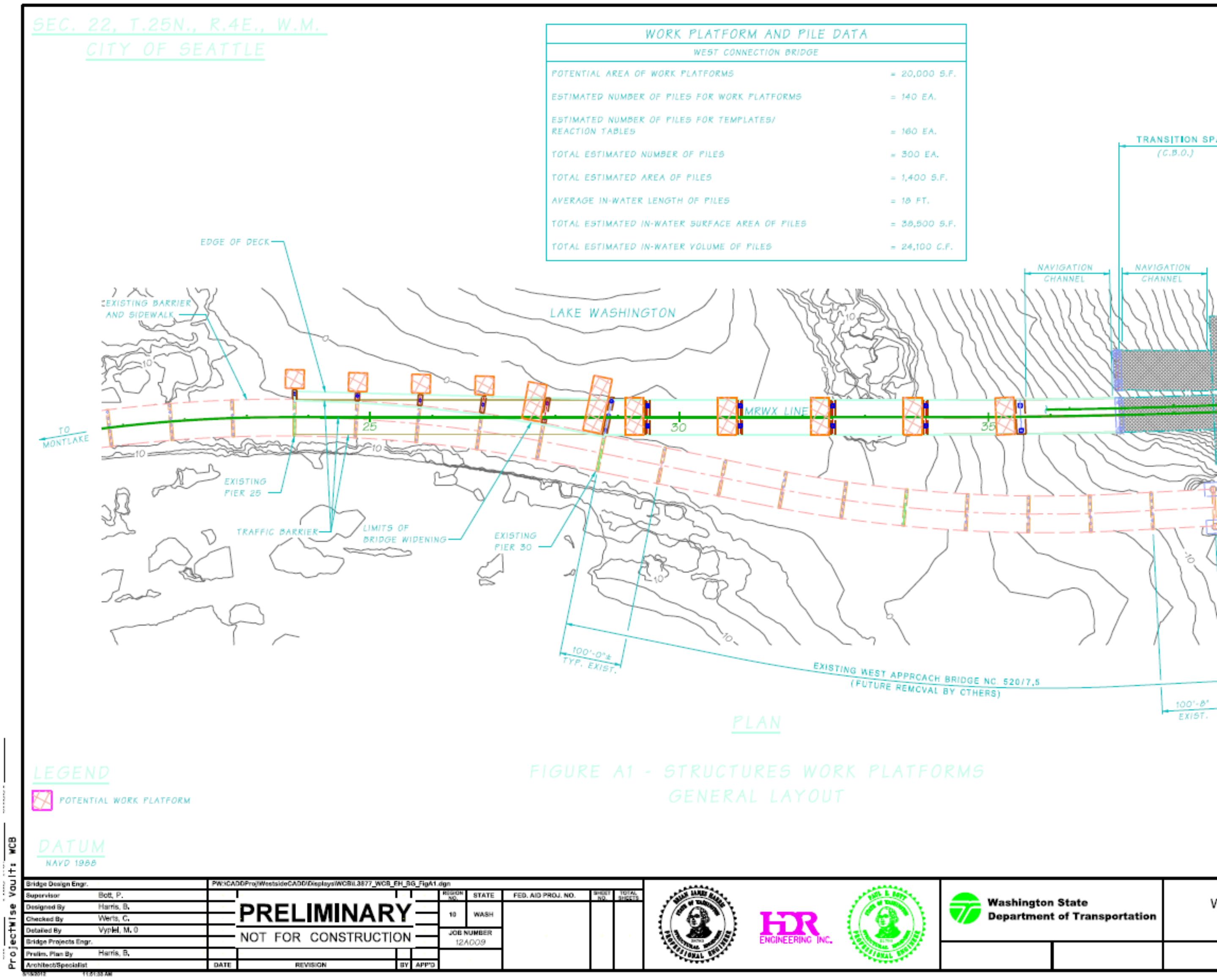

Figure 2-1The West Connection Bridge (WCB) is a 4-lane interim connection between the existing SR 520 west approach bridge and the new SR 520 floating bridge. The Project includes constructing a pre-stressed concrete girder bridge, drilled shaft foundations, and removing a portion of the existing bridge. The widened portion of the WCB is about 500 feet long, while the independent portion is about 850 feet long, for a total of about 1,350 feet**Error! Reference source not found.**.

The expected noise- and vibration-generating construction activities for the WCB are:

Pile Installation for Work Platforms and Drilled Shaft Templates

Work platforms are temporary structures built to provide access for over-water construction. They are needed to support construction equipment and personnel in areas where barges cannot provide adequate support. In this case they would be used for drilled shaft construction. In addition drilled shaft templates may be needed to provide stability for shaft casings during drilled shaft installation. Shaft templates are frames used to guide the drilled shaft casing to ensure that they are placed in the proper location and vertical alignment.

Work platforms and drilled shaft templates would be built on driven piles installed north of the existing bridge from a barge-mounted crane or a mobile crane on a barge. Each work platform segment is expected to be 28 to 30 feet wide by 30 feet long based on normal construction practices and readily available materials. Work platforms at single-column piers would consist of a single segment while piers with multiple columns would have larger work platforms with lengths in multiples of 30 feet.

Figure 2-1 below shows a possible layout of the temporary work platforms. The construction equipment assumed for work platform installation is based on the means and methods described in the West Connection Bridge Work Platforms and Piling Technical Memorandum, June 2012, but may change or be adjusted in the future.

Piles would likely be installed by a combination of two different methods: Impact driving and vibrating. A brief description of each method is presented below:

Impact Driving**:** This method involves impacting the top (head) of the pile with a large hammer until it develops the desired bearing strength and/or tip elevation. This is the most common and versatile type of pile installation. Impact driving can be performed on a wide variety of pile types and sizes and in almost any soil type. It can also be used successfully where there are many different soil types encountered during the driving of a single pile. Impact driving is the only commonly used installation method that allows for a bearing capacity estimation of each pile. The confirmation of bearing capacity for each pile is important to ensure the safety of workers and the nearby traveling public. Large forces are placed on the work platforms by the massive equipment used for drilled shaft installation and failure of the supporting piles could lead to catastrophic collapse of cranes or other equipment.

Vibrating**:** This method involves using a vibratory pile driver to create rapid succession of impacts that liquefy and loosen the soils. The vibratory driver is also designed with heavy steel weights that load the pile and help push it into the ground. This method is best suited for wet sandy or gravelly soils that contain water, but can be used in a variety of mixed soils with some success. The main disadvantages of this method are:

- The inability to penetrate into hard and/or dense soils.
- The inability to estimate bearing capacity upon completion of driving.

Because of these issues vibrating cannot be used as the sole installation method. The potential exists to use vibratory driving for the initial stages of pile driving and finish off with impact driving to set and "proof" (confirm the bearing capacity of) the pile.

The Contractor may choose to construct multiple work platforms and shaft templates at one time for each drilling operation. The likely sequencing would include a completed work platform and template being actively used by a drilled shaft rig with other platforms and templates in various stages of construction or removal. After removal, the work platform and template elements would be "leapfrogged" ahead to the next pier so that the drilling equipment always has an available work platform and template to move to.

When removing the work platforms and shaft templates, temporary piles located directly adjacent to the existing west approach bridge would be cut off a minimum of two feet below the mud line. All other temporary piles could be pulled out by attaching a vibratory pile driving hammer to the top of the pile and simultaneously vibrating and lifting the pile. Exceptionally stubborn piles that cannot be pulled out would instead be cut off a minimum of 2 feet below the mud line.

Existing Bridge Rail Demolition on North Side of West Approach Bridge

In order to tie the WCB to the existing west approach bridge from Pier 25 to Pier 30 approximately 500 feet of bridge rail needs to be demolished along the northern edge of the existing bridge. It is assumed that a mounted hammer hoe ram and pneumatic chipping guns would be used for the demolition work.

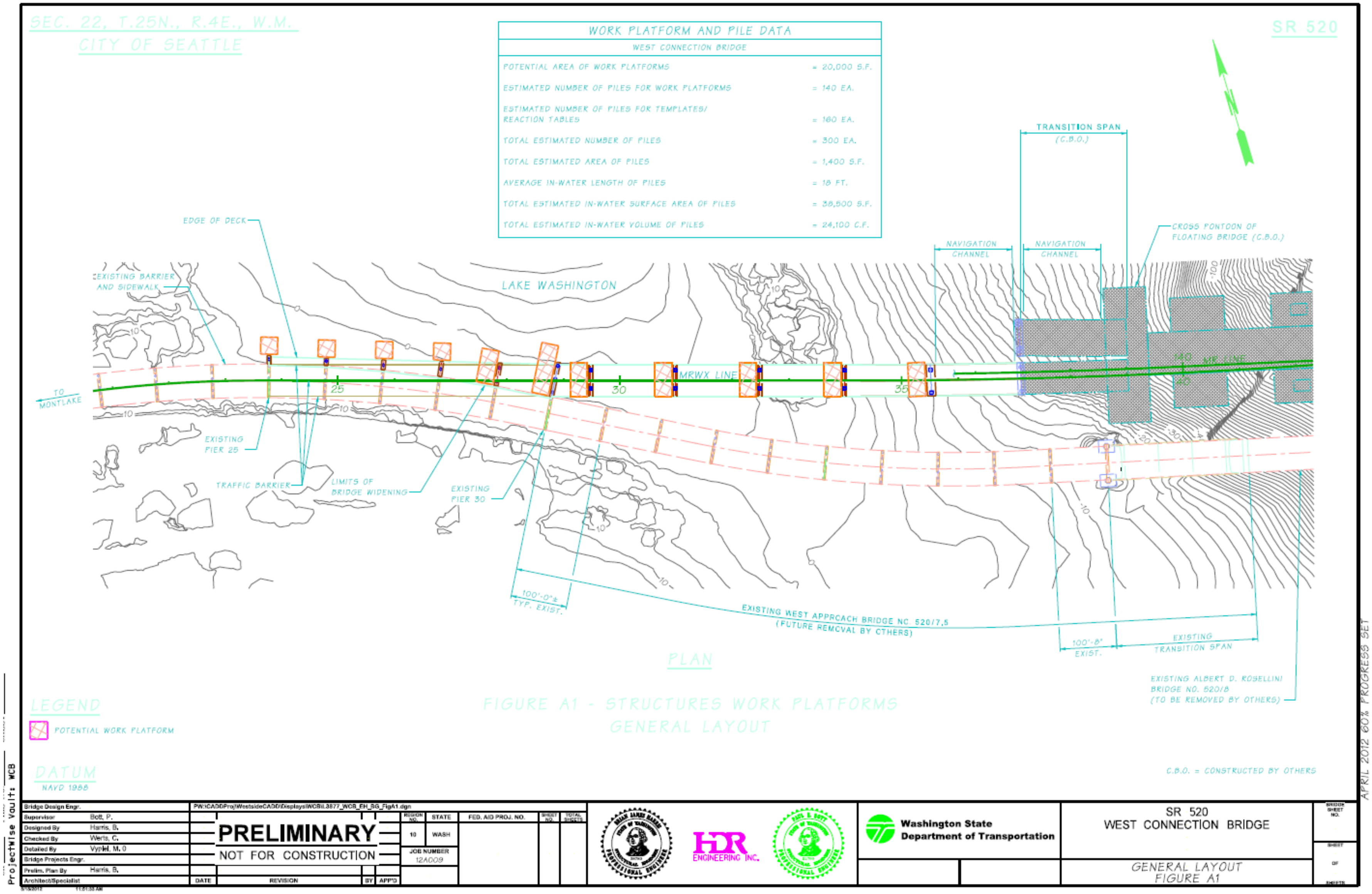

Figure 2-1: General Layout of Work Platforms

3 *Receivers Affected by Construction Noise and Vibration*

Properties having the potential to be affected during construction were identified in the Final Environmental Impact Statement SR 520 Bridge Replacement and HOV Program, SR 520, I-5 to Medina: Bridge Replacement and HOV Project, and the Section 106 Programmatic Agreement between FHWA/WSDOT and the Washington State Historic Preservation Officer. The two closest receivers to the Project construction are the Edgewater Condominiums, a historic property 340 feet from the nearest construction activities (see Figure 7-2) and the Canterbury Shores Condominiums non-historic multi-family residential buildings 550 feet from construction activities (see Figure 7-1).

4 *Construction Noise Limits*

All construction activities presented in this Report take place within the limits of the City of Seattle. The City of Seattle noise limits are based on the Washington State Administrative Code WAC 173-60-040 Maximum Permissible Environmental Noise Levels (WAC 173-60) that applies to general construction activities. This section presents the noise thresholds adopted by the City, relevant exemptions, and information on noise variances.

4.1 Daytime Noise Limits

The Administrative Code of the City of Seattle for noise control is covered under Ordinance 102228, Chapter 25.08. (Section 25.08.410 of the ordinance requires that exterior sound levels be limited to the values shown in Table 4-1. The levels should be measured from the real property of another person or at a distance of fifty (50) feet from the equipment, whichever is greater. The daytime noise limits for the WCB Project is based on the sound source and the receiving property both in a residential district (55 dBA).

Table 4-1: Seattle Noise Ordinance Maximum Permissible Sound Levels

District of Sound Source	District of Receiving Property Within the City of Seattle		
	Residential (dBA)	**Commercial (dBA)**	**Industrial (dBA)**
Residential	55	57	60
Commercial	57	60	65
Industrial	60	65	70

Note: Between the hours of 10:00 p.m. and 7:00 a.m. during weekdays and 10:00 p.m. and 9:00 a.m. during weekends, and legal holidays the levels in Table 4-1 are reduced by 10 dBA (Section 25.08.420).

Section 25.08.425 regulates the noise levels of construction and equipment operations. Levels in Table 4-1 may be exceeded between the hours of 7:00 a.m. and 10:00 p.m. on weekdays and between the hours of 9:00 a.m. and 10:00 p.m. on weekends by no more than the following dBAs for the following types of equipment which are added to the 55 dBA limit in Table 4-1:

1. 25 dBA 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;

2. 20 dBA for portable powered equipment used in temporary locations in support of construction activities or used in the maintenance of public facilities, including but not limited to chainsaws, log chippers, lawn and garden maintenance equipment and powered hand tools; or
3. 15 dBA 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.

Noise Limits for Impact Equipment

Sound created by impact types of construction equipment, including but not limited to pavement breakers, pile drivers, jackhammers, sandblasting tools, or other types of equipment or devices which create impulse noise or impact noise or are used as impact equipment, as measured at the property line or 50 feet from the equipment (whichever is greater), may exceed the maximum permissible sound levels described above in any one-hour period between the hours of 8:00 a.m. and 5:00 p.m. on weekdays and 9:00 a.m. and 5:00 p.m. on weekends, but in no event is to exceed the following:

Leq = 90 dBA continuously;

Leq = 93 dBA for 30 minutes;

Leq = 96 dBA for 15 minutes;

Leq = 99 dBA for 7.5 minutes;

Sound levels in excess of Leq= 99 dBA are prohibited unless authorized by variance.

The standard of measurement is a one-hour Leq measured for times not less than one minute to project an hourly Leq.

4.2 Nighttime Noise Limits

When construction activities occurring during nighttime hours (weekdays from10:00 p.m. to 7:00 a.m. and weekends and legal holidays from 9:00 a.m. to 10:00 p.m.) are anticipated to exceed the maximum permissible levels established by Section 25.08.420 of the Seattle Noise Ordinance (Table 4-1 and associated Note), a noise variance is required. It is expected that the Contractor will need to work during nighttime hours for limited periods of time. WSDOT will obtain the required noise variances from the City of Seattle.

5 *Construction Vibration Thresholds*

Construction vibration can be assessed for different potential effects:

- Human response
- Building damage

5.1 Human Response

One of the major problems in developing suitable criteria for ground-borne vibration is that there has been relatively little research into the human response to vibration, in particular, human annoyance from building vibration. The American National Standards Institute (ANSI) developed criteria for evaluating human exposure to vibration in buildings in 1983[1]. The International Organization for Standardization (ISO) adopted similar criteria in 1989[2] and revised them in 2003[3]. The 2003 version of ISO 2361-2 acknowledges that "human response to vibration in buildings is very complex." It further indicates that the degree of annoyance cannot always be explained by the magnitude of the vibration alone. Other phenomena such as noise, rattling, visual effects, like the movement of hanging objects and time of day (e.g., late at night) all play some role in the response. To understand and evaluate human response, which is often measured by complaints, all of these related effects need to be considered. The available data documenting real world experience with these phenomena is still relatively sparse.

Table 5-1 is a summary of the human response to different levels of vibration. In this table, both the root mean square (rms) vibration velocity levels used to assess human annoyance and the corresponding peak particle velocity (PPV) levels, used to measure construction vibration, are presented. A crest factor of 4 (representing a PPV-rms difference of 12 VdB) has been used to calculate the approximate PPV from the rms vibration velocity levels. For evaluating potential annoyance or interference with human activities due to construction vibration, the Federal Transit Administration criteria for General Assessment can be applied in most cases. General Assessment criteria is 72 VdB for residential uses and 75 VdB for institutional/office uses.

Table 5-1: Human Response to Different Levels of Ground-Borne Vibration

PPV	RMS Vibration Velocity Level	Human Response
0.007 in/sec (77 VdB)	65 VdB	Approximate threshold of perception for many humans.
0.022 in/sec (87 VdB)	75 VdB	Approximate dividing line between barely perceptible and distinctly perceptible.
0.07 in/sec (97 VdB)	85 VdB	Vibration acceptable only if there are an infrequent number of events per day.

Source: *Transit Noise and Vibration Impact Assessment*, FTA, May 2006.

[1] American National Standards Institute, Guide to the Evaluation of Human Exposure to Vibration in Buildings. ANSI S3.29-1983.
[2] International Organization for Standardization, "Mechanical Vibration and Shock : Evaluation of human exposure to whole body vibration: Part 2 – Vibration in buildings (1 to 80 Hz), ISO 26312-2003.
[3] International Organization for Standardization, "Evaluation of Human exposure to whole body vibration: Part 2 – Continuous and shock-induced vibration in buildings (1 to 80 Hz), ISO 2361-21989.

Numerous other studies have been conducted to characterize the human response to vibration. These studies have concluded that continuous vibration from construction equipment such as roadway graders, backhoes, and dozers can be tolerated at higher vibration levels than transient vibration generated by impact pile driving.

Table 5-2 summarizes the results of another study that relates human response to transient vibration, which could be generated by any type of impact equipment such as impact pile driving. These levels of human response are more appropriate for the WCB Project since the highest levels of construction vibration are generated by impact activities such as pile driving and from demolition using hoe rams.

Table 5-2: Human Response to Transient Vibration

PPV (in/sec)	Human Response
2.0	Severe
0.9	Strongly perceptible
0.24	Distinctly perceptible
0.035	Barely perceptible

Source: Transportation- and Construction Induced Vibration Guidance Manual, Caltrans June 2004.

5.2 Building Damage Risk Criteria

The primary concern regarding construction vibration relates to potential damage effects. Guidelines on vibration damage criteria are given in Table 5-3 for various structural categories[4]. These limits should be viewed as criteria to identify problem locations that must be addressed during construction. The upper limit of damage risk is structural damage to building foundations. The U.S. Bureau of Mines structural damage threshold (not shown in the table) is 2.0 inches/sec.

Table 5-3: FTA Construction Vibration Damage Criteria[5]

Building Category	PPV (in/sec)
I. Reinforced-concrete, steel or timber (no plaster)	0.5
II. Engineered concrete and masonry (no plaster)	0.3
III. Non-engineered timber and masonry buildings	0.2
IV. Buildings extremely susceptible to vibration damage	0.12

Source: *Transit Noise and Vibration Impact Assessment*, FTA, May 2006.

[4] David A. Towers, "Ground-borne Vibration from Slurry Wall Trench Excavation for the Central Artery/Tunnel Project Using Hydromill Technology," Proc. InterNoise 95, Newport Beach, CA, July 1995.
[5] Swiss Consultants for Road Construction Association, "Effects of Vibration on Construction," VSS-SN640-312a, Zurich, Switzerland, April 1992.

6 *Construction Noise Predictions*

6.1 Noise Prediction Methodology

The projected daytime and nighttime construction noise levels were modeled using CadnaA version 4.0, a three dimensional graphics oriented program that uses the International Standards Organization (ISO) 9613, a general purpose standard for outdoor noise propagation. CadnaA incorporates the following elements:

- An emission model to determine the noise generated by the equipment at a reference distance.
- A propagation model that shows how the noise level varies with distance.
- A way of summing the noise of each piece of equipment at noise sensitive locations.
- Includes the effects of topography, ground cover, and shielding from building structures that are input by the user.

The average noise emissions in Table 6-1 for the different categories of construction equipment are based on the levels used in the Federal Highway Administration noise modeling program "*Roadway Construction Noise Model*" (RCNM) and measured equipment noise levels from actual construction projects. Measured noise levels were used for the noise modeling in this Report when they were higher than the noise levels in the RCNM.

The noise models in this Report represent the worst-case noise level (Lmax) for each construction activity. The worst-case model for impact equipment (pile drivers, hoe rams) assumes continuous use of the equipment. For construction activities where several pieces of equipment are modeled, all equipment is assumed to be operating simultaneously and continuously. This is considered worst-case because it is not expected that impact equipment will be used continuously for extended periods, nor is all the other modeled equipment expected to be operating simultaneously and continuously.

Table 6-1: Reference Noise Levels of Construction Equipment

Equipment Description	Lmax Noise Limit at 50 ft, dB Slow	Actual Measured Lmax at 50 ft, dB Slow	Is Equipment an Impact Device?
Auger Drill Rig	85 dBA	84 dBA	No
Backhoe	80 dBA	78 dBA	No
Boring Jack Power Unit	80 dBA	83 dBA	No
Chain Saw	85 dBA	84 dBA	No
Clam Shovel	93 dBA	87 dBA	Yes
Compactor (ground)	80 dBA	83 dBA	No
Compressor (air)	80 dBA	78 dBA	No
Concrete Mixer Truck	85 dBA	79 dBA	No
Concrete Pump Truck	82 dBA	81 dBA	No
Concrete Saw	90 dBA	90 dBA	No
Crane (mobile or stationary)	85 dBA	81 dBA	No
Dozer	85 dBA	82 dBA	No
Dump Truck	84 dBA	76 dBA	No
Excavator	85 dBA	81 dBA	No
Flat Bed Truck	84 dBA	74 dBA	No
Front End Loader	80 dBA	79 dBA	No
Generator (25 KVA or less)	70 dBA	81 dBA	No
Generator (more than 25 KVA)	82 dBA	73 dBA	No
Gradall	85 dBA	83 dBA	No
Horizontal Boring Hydraulic Jack	80 dBA	82 dBA	No
Impact Pile Driver (diesel or drop)	95 dBA	101 dBA	Yes
Jackhammer	85 dBA	89 dBA	Yes
Mounted Impact Hammer (hoe ram)	90 dBA	90 dBA	Yes
Paver	85 dBA	77 dBA	No
Pickup Truck	55 dBA	75 dBA	No
Pneumatic Tools	85 dBA	85 dBA	No
Pumps	77 dBA	81 dBA	No
Rock Drill	85 dBA	81 dBA	No
Scraper	85 dBA	84 dBA	No
Slurry Plant	78 dBA	78 dBA	No
Slurry Trenching Machine	82 dBA	80 dBA	No
Soil Mix Drill Rig	80 dBA	--	No
Tractor	84 dBA	82 dBA	No
Vacuum Excavator (Vac-Truck)	85 dBA	85 dBA	No
Vacuum Street Sweeper	80 dBA	82 dBA	No
Vibratory Concrete Mixer	80 dBA	80 dBA	No
Vibratory Pile Driver	95 dBA	101 dBA	No
Welder	73 dBA	74 dBA	No
Source: FHWA Roadway Construction Noise Model, January 2006			

6.2 Predicted Noise Levels and Impact Assessment

The major expected noise generating construction activities are removal/demolition of a portion of the existing bridge using a mounted hammer hoe ram and impact pile driving for construction of temporary work platforms and drilled shaft templates. The worst case predicted noise levels for these construction activities are presented in Figure 6-1 through Figure 6-3 below. The predicted noise levels are summarized in Table 6-2. Key observations from the modeling results are:

- Mounted Hammer Hoe Ram: Demolition of the existing bridge will be within 340 feet of the facade of the nearest residence (the Edgewater Condominiums). The next closest residential development (the Canterbury Shores Condominiums), is 550 feet from the demolition site on the existing bridge. Predicted noise contour levels are shown in Figure 6-1. The predicted worst-case noise levels (Lmax) at these closest residences is 79 dBA and 78 dBA, respectively. These levels do not exceed the City of Seattle noise limit for continuous impact activities (90 dBA).
- Impact Pile Driver: The WCB will be north of the existing bridge, farther than the existing bridge to the nearest residences. The closest pile driving to the Edgewater Condominiums is at the east end of the WCB about 340 feet from the facade of the nearest building (predicted contour levels are shown in Figure 6-2). The closest pile driving to the Canterbury Shores Condominium building is at the west end of the WCB about 560 feet from its facade (predicted noise contour levels are shown in Figure 6-3). The predicted worst-case noise levels (Lmax) are 86 dBA and 83 dBA, respectively. These levels do not exceed the City of Seattle noise limit for continuous impact activities (90 dBA).

Table 6-2: Predicted Noise Levels for WCB Construction Activities

Equipment	Receiver	Location	Predicted Lmax, dBA
Mounted Hammer Hoe Ram (demolition)	1	2411 42nd Avenue East (Edgewater Condominiums)	79 dBA
	2	2501 Canterbury Lane East (Canterbury Shores Condominiums)	78 dBA
Impact Hammer (pile driving)	1	2411 42nd Ave East (Edgewater Condominiums)	86 dBA
	2	2501 Canterbury Lane East (Canterbury Shores Condominiums)	83 dBA

Figure 6-1: Predicted Noise Contours for Mounted Hammer Hoe Ram, West Connection Bridge

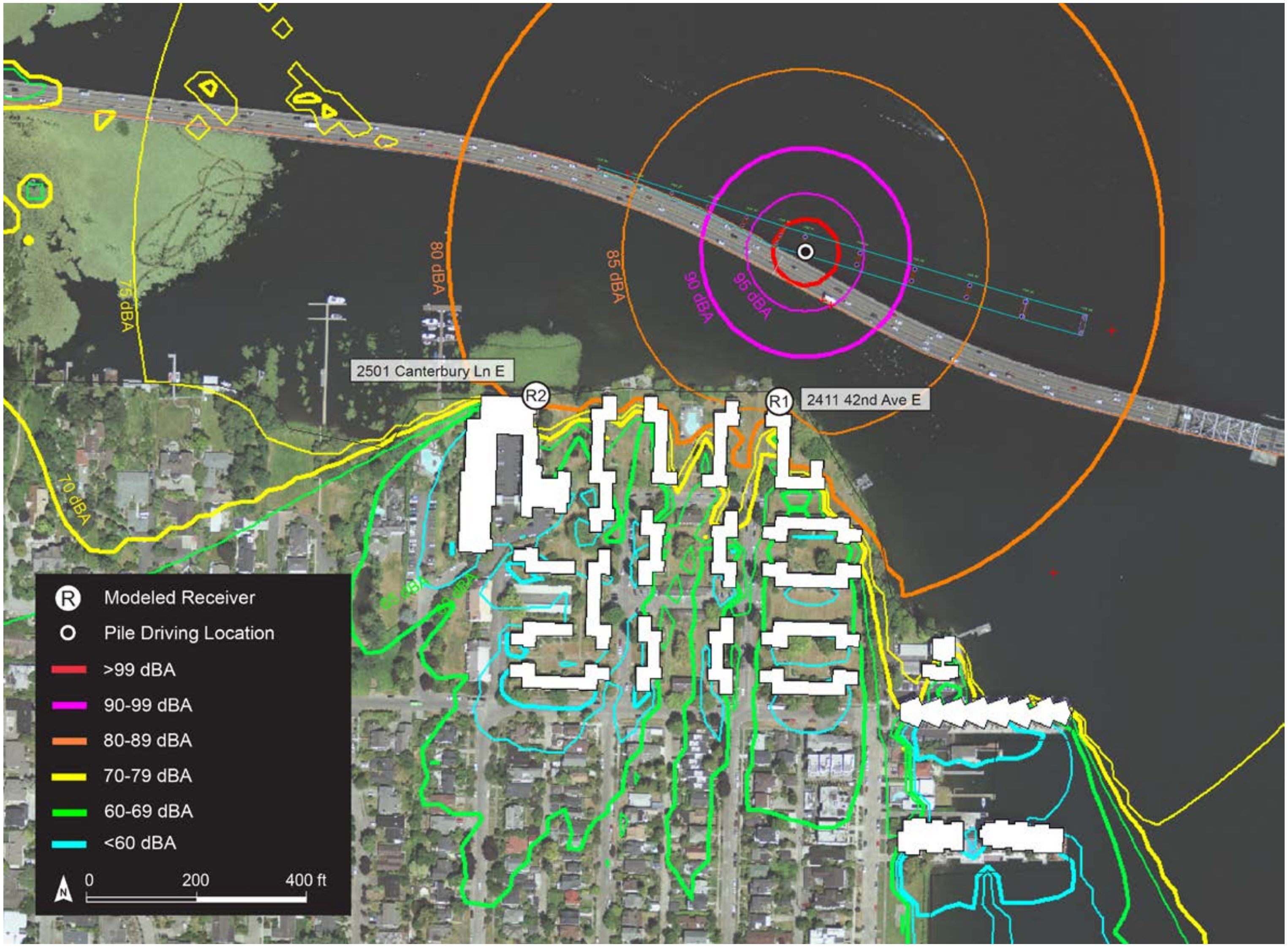

Figure 6-2: Predicted Noise Contours for Pile Driving, East End of West Connection Bridge

Figure 6-3: Predicted Noise Contours for Pile Driving, West End of West Connection Bridge

7 *Construction Vibration Predictions*

7.1 Vibration Prediction Methodology

For this study, the FTA analytical/empirical vibration prediction method was used to estimate the vibration levels that might propagate from the construction equipment to the vibration sensitive locations. The vibration model and related levels in Table 7.1 are based on a combination of several previous works including measured equipment vibration emission data from the Federal Transit Administration and the Central Artery/Tunnel Project in Boston, and ground transmissibility relationships found in Charles Dowding's reference textbook Construction Vibrations[6]. The fundamental equation used in the model is based on propagation relationships of vibration through average soil conditions and distance, as follows:

$$PPV_{equipment} = PPV_{ref}\ (100/D_{rec})^n$$

Where:

PPV_{ref} = reference PPV at 100 ft.
D_{rec} = distance from equipment to the receiver in ft.
n = 1.1 (the value related to the attenuation rate through ground)

The suggested value for "n" is 1.1. Modifying the value of "n" based on soil classification is not necessary because the modeling presented in this study is intended to predict the most conservative, or highest, vibration levels for different construction activities. Vibration monitoring during construction will more accurately determine these actual values.

Vibration emission levels (PPVref) used in the model is shown in Table 7-1. The levels presented in the table are from measurements from several projects including the Central Artery/Tunnel Project in Boston and from several published sources including the FTA Manual and Dowding's Textbook.

[6] Dowding, Charles, Construction Vibrations, Prentice Hall, Upper Saddle River, NJ, 1996.

Table 7-1: Equipment Vibration Emission Levels

Equipment Description	Vibration Type Steady or transient	Ref PPV at 100 ft.
Auger Drill Rig	Steady	0.011125
Backhoe	Steady	0.011
Bar Bender	Steady	N/A
Boring Jack Power Unit	Steady	N/A
Chain Saw	Steady	N/A
Compactor	Steady	0.03
Compressor	Steady	N/A
Concrete Mixer	Steady	0.01
Concrete Pump	Steady	0.01
Concrete Saw	Steady	N/A
Crane	Steady	0.001
Dozer	Steady	0.011
Dump Truck	Steady	0.01
Excavator	Steady	0.011
Flat Bed Truck	Steady	0.01
Front End Loader	Steady	0.011
Generator	Steady	N/A
Gradall	Steady	0.011
Grader	Steady	0.011
Horizontal Boring Hydraulic Jack	Steady	0.003
Hydra Break Ram	Transient	0.05
Impact Pile Driver	Transient	0.2
Insitu Soil Sampling Rig	Steady	0.011125
Jackhammer	Steady	0.003
Mounted Hammer hoe ram	Transient	0.18975
Paver	Steady	0.01
Pickup Truck	Steady	0.01
Pneumatic Tools	Steady	N/A
Scraper	Steady	0.000375
Slurry Trenching Machine	Steady	0.002125
Soil Mix Drill Rig	Steady	0.011125
Tractor	Steady	0.01
Tunnel Boring Machine (rock)	Steady	0.0058
Tunnel Boring Machine (soil)	Steady	0.003
Vibratory Pile Driver	Steady	0.14
Vibratory Roller (large)	Steady	0.059
Vibratory Roller (small)	Steady	0.022
Welder	Steady	N/A
Concrete Batch Plant	Steady	N/A
Pumps	Steady	N/A
Blasting	Transient	0.75
Clam Shovel	Transient	0.02525
Rock Drill	Steady	0.011125
3-ton truck at 35 mph	Steady	0.0002

7.2 Predicted Vibration Levels and Impact Assessment

The following section presents the predictions of vibration levels at historic and non-historic buildings closest to the main vibration generating activities in each of the construction areas identified in Section 2. The following vibration criteria are recommended to avoid or limit damage risk to the properties during construction:

- Historic properties – Yellow flag limit of 0.12 inches/second PPV and red flag limit of 0.30 inches/second PPV
- Non-historic properties – Yellow flag limit of 0.40 inches/second PPV and red flag limit of 0.50 inches/second PPV

As previously stated, the two closest receivers to the Project construction are the Edgewater Condominiums and the Canterbury Shores Condominiums. In this case because the two properties are directly adjacent to each other the criteria for historic properties should take precedence.

If the historic property yellow flag exceedance occurs, all necessary measures should be taken to prevent any higher vibration levels from occurring.

If the historic property red flag level is exceeded, all work should be stopped immediately and the Edgewater Condominiums should be checked to determine if any damage has occurred. If the red flag limit is exceeded during construction, there is a risk of cosmetic damage and, at higher levels, structural damage to buildings. It is recommended that vibration monitors provide an alert if the yellow flag limit is exceeded.

Table 7-2 presents the distance beyond which the vibration damage risk criteria would not be exceeded by equipment likely to be used for the Project. Most of the equipment can be operated without risk of damage at distances greater than 12 feet from historic buildings or at distance greater than 4 feet from non-historic buildings. The exceptions are the mounted hammer hoe ram, impact pile driver, and vibratory pile driver, which have further distances to impact thresholds.

Table 7-2: Distance to Construction Yellow Flag Vibration Impact Thresholds

Equipment	Reference PPV (in/sec) at 100 ft	Distance to Impact Threshold of 0.40 in/sec PPV	Distance to Impact Threshold of 0.12 in/sec PPV
Auger Drill Rig	0.001	4 ft	12 ft
Cranes	0.001	1 ft	2 ft
Dozer	0.011	4 ft	12 ft
Dump Truck	0.01	4 ft	11 ft
Front End Loader	0.011	4 ft	12 ft
Impact Pile Driver	0.20	55 ft	160 ft
Jackhammer	0.003	1.5 ft	4 ft
Mounted Hammer Hoe Ram	0.18975	55 ft	152 ft
Vibratory Pile Driver	0.14	40 ft	115 ft
Notes: Predicted vibration levels will not exceed the impact threshold when the distance between a building and the construction equipment is greater than the 'Distance to Impact Threshold'.			

The expected major vibration generating construction activities are the same as those generating the most noise. These include removal/demolition of a portion of the existing bridge using a mounted hammer hoe ram and impact pile driving for construction of temporary work platforms drilled shaft templates. The worst case predicted vibration contours for these construction activities are presented in Figure 7-1 and Figure 7-2 below. The graphics also show recommended monitoring locations.

Table 7-3 summarizes the predicted vibration levels based on observations from the modeling results, as follows:

- Mounted Hammer Hoe Ram (Figure 7-1): Demolition of the existing bridge will not be closer than 340 feet from the nearest structure. The predicted vibration level at this distance is 0.037 in/sec PPV which is below the yellow flag damage risk threshold for historic properties (0.12 in/sec PPV). However, at this level, the construction vibration will be distinctly perceptible to the nearest residences and could trigger complaints.
- Vibratory Pile Driver (Figure 7-2): The WCB will be north of the existing bridge. Impact pile driving will not be closer than 340 feet from the nearest structure. The predicted level at this distance is 0.050 in/sec PPV which is below the yellow flag damage risk threshold for historic properties (0.12 in/sec PPV). However, at this level the construction vibration will be distinctly perceptible to the nearest residences and could trigger complaints.

Table 7-3: Predicted Vibration Levels for WCB Construction Activities

Equipment	Receiver	Location	Distance (ft)	Predicted Lmax, PPV (in/sec)
Mounted Hammer Hoe Ram (demolition)	1	2411 42nd Avenue East (Edgewater Condominiums)	340 ft	0.037 in/sec
	2	2501 Canterbury Lane East (Canterbury Shores Condominiums)	550 ft	0.029 in/sec
Impact Hammer (pile driving)	1	2411 42nd Ave East (Edgewater Condominiums)	340 ft	0.052 in/sec
	2	2501 Canterbury Lane East (Canterbury Shores Condominiums)	560 ft	0.030 in/sec

Figure 7-1: Predicted Vibration Contour for Mounted Hammer Hoe Ram, West Connection Bridge

Figure 7-2: Predicted Vibration Contour for Vibratory Pile Driving, East End of West Connection Bridge

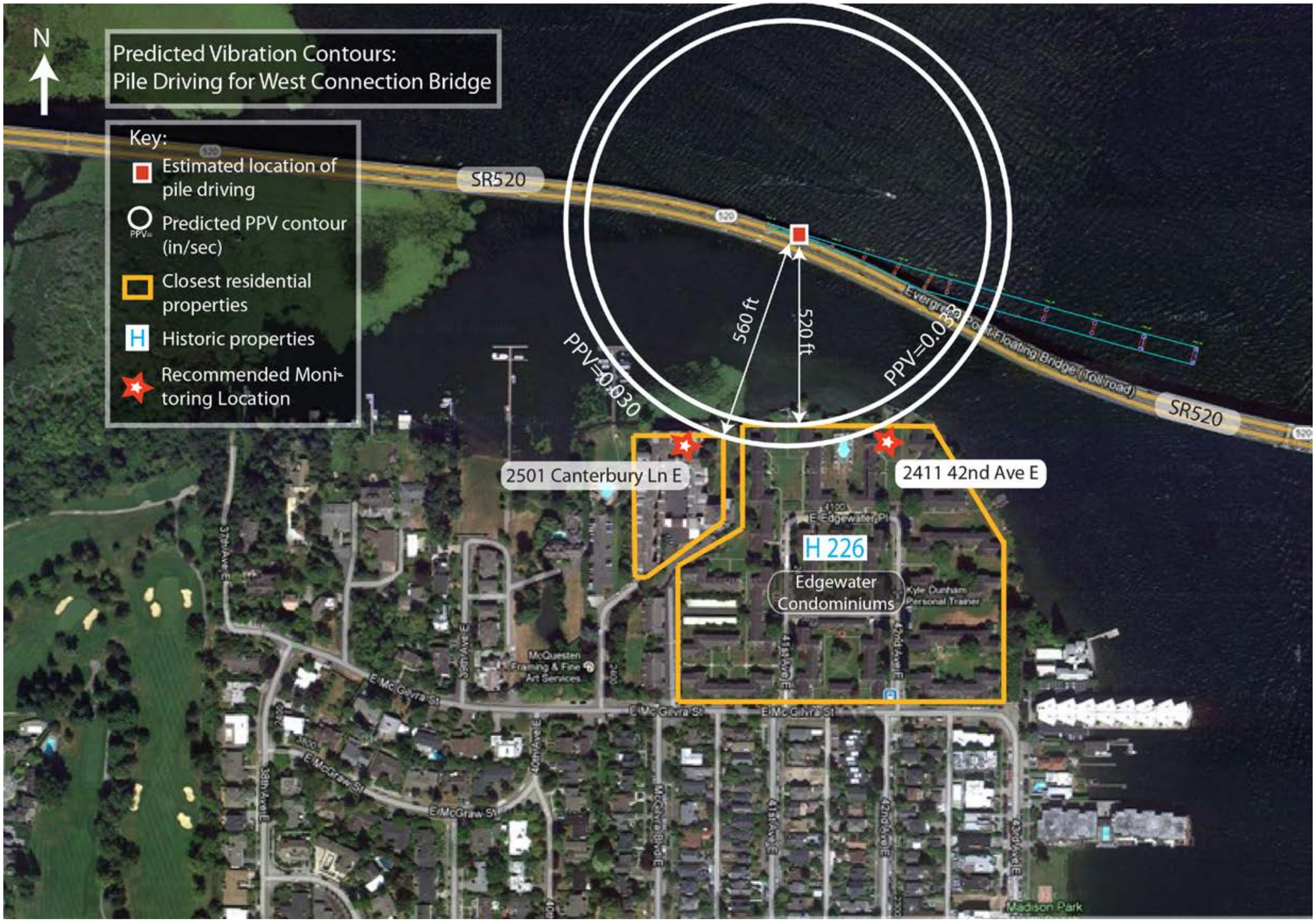

Figure 7-3: Predicted Vibration Contours for Vibratory Pile Driving, West End of West Connection Bridge

8 *Mitigation Measures*

No noise or vibration impacts are predicted for West Connection Bridge construction activities. Therefore, no site specific mitigation measures are recommended. However, the Contractor should implement the general noise and vibration control measures at all sites as well as perform monitoring at the closest receivers. Recommendations for vibration monitoring during the Project are presented in Section 9.

8.1 General Noise and Vibration Control Measures

When day time construction noise exceeds the limits set forth by the Seattle Noise Ordinance the Contractor should stop construction until either temporary noise control measures can be implemented or the means and methods of construction can be modified to lower the noise.

As standard best practices the Contractor should implement the following noise control measures in addition to WSDOT standard methods:

- Ensure that all equipment is properly maintained so parts don’t rattle or bang.
- Line or cover storage bins, conveyors, and chutes with sound deadening material.
- Equip noise-producing equipment with acoustically attenuating shields or shrouds recommended by the manufacturers when necessary.
- Impact or impulse tools should not be used from 5:00 p.m. to 8:00 a.m. weekdays and 5:00 p.m. to 9:00 a.m. weekends.
- Limit the use of public address systems during nighttime hours, except for emergency notifications.

Where the vibration levels exceed 0.12 in/sec PPV at the monitoring locations, all necessary measures should be taken to modify the means and methods of construction to reduce the vibration levels. If 0.30 in/sec PPV is exceeded, all work should be stopped immediately and the Edgewater Condominiums property assessed for damage. .

In an effort to reduce vibration during construction, the contractor should be required to implement the following practices:

- Use as small an impact device (i.e., hoe ram, pile driver) as possible to accomplish necessary tasks while minimizing excess vibration
- Select non-impact demolition and/or construction methods such as saw or torch cutting and removal for off-site demolition, chemical splitting, or hydraulic jack splitting instead of high impact methods

8.2 City of Seattle Nighttime Noise Variance Conditions

The City of Seattle has granted 8 14-day variances to its noise ordinance for nighttime construction on this project. The variance allows the Contractor to exceed the local noise ordinance levels. Unless otherwise approved by the Engineer in writing, nighttime work shall be restricted to the conditions of the variance.

- Except in the case of emergency, whenever the Contractor works between the nighttime hours of 10:00 p.m. and 7:00 a.m. Monday through Friday or between 10:00 p.m. and 9:00 a.m. Saturday through Sunday and exceeds the local ordinance noise levels, the

Contractor shall, in addition to other restrictions of this section or other ordinances, perform the following measures to minimize construction noise:

1. Impact tools such as hoe rams or impulse tools such as Vac trucks are prohibited between the hours of 10:00 p.m. and 7:00 a.m. Monday through Friday and between the hours of 10:00 p.m. and 9:00 a.m. Saturday, Sunday and holidays.
2. The Contractor shall use ambient sensitive backup warning devices on all vehicles. The Contractor may use back-up observers in lieu of pure tone back-up warning devices for all equipment except dump trucks in compliance with WAC Chapter 296-155-610 and 296-155-615. The Contractor shall use back-up observers and back-up warning devices for dump trucks in compliance with WAC Chapter 296-155-610.
3. All trucks performing export haul shall have well maintained bed liners as inspected and approved by the Engineer.
4. Truck tailgate banging is prohibited. All truck tailgates shall be secured to prevent excessive noise from banging.
5. During pavement removal, all material spilled on the roadway shall be removed by hand methods or sweeping. No scraping type equipment shall be used to clean decks or pavement surfaces.
6. Construction and stationary equipment, such as light plants, generators, and compressors, and jackhammers shall utilize WSDOT approved noise mitigation shields, noise blankets, skirts, or other means available as approved by the Engineer.
7. Equipment using horn, alarms or sirens anywhere on site is prohibited.
8. A copy of the variances shall be kept on site at all times.
9. The Contractor shall mail written notification to City of Seattle, Department of Planning and Development and to residents within 500 feet of the nighttime work zone area within the work zone area.. The Contracting Agency shall review and approve the form and content of any noise flyer or notice, prior to distribution by the Contractor. The Engineer will provide noise flyer or notice templates for use by the Contractor. The Contractor shall provide the Engineer the noise flyer or notice, a minimum of 11 working days prior to the start of nighttime work. This submittal time will allow the Engineer time to incorporate the Contractor's project specific information into the final version of the noise flyer or notice. The written notification shall contain the following information:
    - Legal project title, MP location, jurisdiction, description of the project, and description of the items of work to be performed at night by the Contractor.
    - Start date and duration of the nighttime work.
    - List of the expected nighttime noise sources.
    - List of noise mitigation measures to be implemented.
    - WSDOT complaint response phone number.
    - List of WSDOT contact names, email and phone number to refer in case of questions or complaints.

The Engineer will provide the final approved version of the noise flyer or notice, to the Contractor a minimum of 9 working days prior to the start of night work. The Contractor shall distribute by mail delivery the approved noise flyers or notices to residents within 500 feet of the nighttime work zone area a minimum of 7 working days prior to the start of the night work. No noise flyers or notices shall be distributed without approval of the Engineer.

8.3 Outreach to Property Owners

While vibration levels should not exceed thresholds, some vibration from pile driving and demolition is expected to be perceptible at the properties nearest these activities. Proactive outreach to property owners at Canterbury Shores and the Edgewater Condominiums and on the results and mitigation measures outlined in this Report is recommended to reduce the potential for complaints.

9 Vibration Monitoring

9.1 Pre-Construction Building Survey

A pre-construction survey is recommended for setting the baseline for the structural condition of the buildings closest to the project. Recommended locations are outlined with a dashed line on Figure 9-1 and include the northern row of buildings in the Edgewater Condominium complex and the Canterbury Shores Condominium buildings.

A preconstruction survey typically includes inspecting building foundations, exterior walls, driveways, sidewalks, hardscape elements, and interior floors and walls documenting any pre-existing defects such as cracks, settlement, subsidences, corrosions, or water damage. The inspection can be documented by photographing or videotaping the elements of the property under inspection. Any defects that warrant monitoring during construction should be noted and, if appropriate, should have crack monitors installed prior to construction.

9.2 Vibration Monitoring During Construction

The primary goal of monitoring is to verify that vibration limits are not exceeded. There are two recommended monitoring locations: 2501 Canterbury Lane East and 2411 42nd Avenue East. The monitors should be located at the outside of the buildings in a locked case. They should be capable of measuring continuous data unattended and sending the data by wireless modem to several different parties including the WSDOT Project Engineer to ensure that the levels do not exceed the thresholds defined in this report. The monitors should also be capable of generating an e-mail alert when the thresholds are exceeded so immediate corrective action can be taken.

It is recommended that vibration monitors provide alerts when 0.12 inches/second PPV and 0.30 inches/second are exceeded. If a 0.30 inches/second PPV exceedance occurs at the Edgewater Condominiums property, potential damage from vibration should be assessed. A visual inspection of the property should be made to verify that there are no damages developing or occurring as a result of the vibration.

Vibration Monitoring Plan

A Vibration Monitoring Plan will need to be prepared, stamped, and administered by an acoustical engineer. The Vibration Monitoring Plan should include the vibration instrumentation, location of vibration monitors, data acquisition, and exceedance notification and reporting procedures.

<u>Vibration Instrumentation:</u> Vibration monitors shall be capable of measuring maximum root-mean-square (rms) unweighted peak particle vibration velocity (PPV) levels triaxially in three directions over a frequency range of 1 to 100 Hz. The monitors shall be Instantel Blastmate Series 3 seismographs or approved equal with triaxial geophones. The monitors shall be equipped with cellular modems for internet communication and use the auto call home feature to automatically email daily reports or exceedance notifications to the WSDOT Project Engineer or designee. The vibration monitor will be set to automatically record daily events during working hours and to record peak triaxial PPV values in 5 minute interval histogram plots. The method of coupling the geophones to the ground will be described. Procedures to calibrate vibration monitors for certified laboratory conformance at least once a year will be provided.

Location of Vibration Monitors: Prepare and submit a scaled plan indicating monitoring locations, including measurements to be taken at construction site boundaries and at nearby historic and non-historic properties.

Data Acquisition: The information to be provided in the data repots will be presented including at a minimum daily histogram plots of PPV vs. time of day for three triaxial directions, the maximum peak vector sum PPV and maximum frequency for each direction, and a USBM R18507 compliance chart of maximum PPV vs. frequency. The reports will also identify construction equipment operating during the monitoring period and their locations and distances to all vibration sensitive locations.

Exceedance Notification and Reporting Procedures: A description of the notification of exceedance and reporting procedures will be included and the follow-up procedures taken to reduce vibration levels to below the allowable limits.

Within 45 days of the Contractors notice to proceed (NTP), the Vibration Monitoring Plan will be submitted to the WSDOT Project Engineer or its designee. At a minimum the vibration monitoring data will be sent to the WSDOT Project Engineer or designee on a weekly basis or sooner if needed. Included will be measurements taken during the previous week. In the event that the measured vibration levels exceed allowable limits, the WSDOT Project Engineer or designee will be immediately notified and any further construction activities will be stopped until either alternative equipment or alternative construction procedures can be used that generate vibration levels that do not exceed the allowable limits.

Figure 9-1: Structures to Include in the Pre-construction Survey

References

1 Federal Transit Administration, Transit Noise and Vibration Impact Assessment, May 2006.

2 Caltrans, Transportation- and Construction Induced Vibration Guidance Manual, June 2004.

APPENDIX A: FUNDAMENTALS OF NOISE AND VIBRATION

A.1 FUNDAMENTALS OF NOISE

Sound is mechanical energy transmitted by pressure waves in a compressible medium such as air. Noise is generally defined as unwanted or excessive sound. Sound can vary in intensity by over one million times within the range of human hearing. Therefore, a logarithmic scale, known as the decibel scale (dB), is used to quantify sound intensity and compress the scale to a more manageable range.

Sound is characterized by both its amplitude and frequency (or pitch). The human ear does not hear all frequencies equally. In particular, the ear deemphasizes low and very high frequencies. To better approximate the sensitivity of human hearing, the A-weighted decibel scale has been developed. A-weighted decibels are abbreviated as “dBA.” On this scale, the human range of hearing extends from approximately 3 dBA to around 140 dBA. As a point of reference, Figure 9-2 includes examples of A-weighted sound levels from common indoor and outdoor sounds.

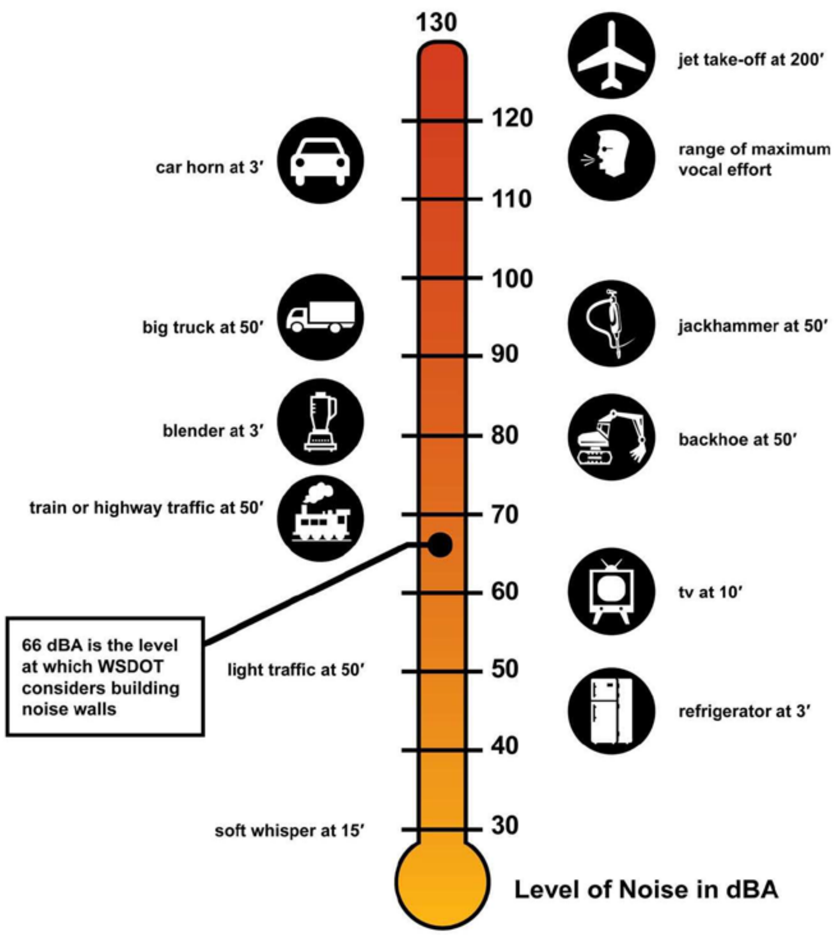

Figure 9-2: Typical Outdoor and Indoor Noise Levels

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

Two of the primary factors that reduce levels of environmental sounds are increasing the distance between the sound source and the receiver and having intervening obstacles, such as walls, buildings, or terrain features that block the direct path between the sound source and the receiver. Factors that act to increase the loudness of environmental sounds include the proximity of the sound source to the receiver, sound enhancements caused by reflections, and focusing caused by various meteorological conditions.

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

- **Equivalent Sound Level (Leq)**: Environmental sound fluctuates constantly. The equivalent sound level (Leq), sometimes referred to as the energy-average sound level, is the most common means of characterizing community noise. Leq represents a constant sound that, over the specified period, has the same sound energy as the time-varying sound.
- **Maximum Sound Level (Lmax):** The maximum sound level over a period of time or for a specific event can also be a useful parameter for characterizing specific noise sources. Standard sound level meters have two settings, FAST and SLOW, which represent different time constants. Lmax using the FAST setting will typically be 1 to 3 dB greater than Lmax using the SLOW setting.
- **Percent Exceedance Level (Lxx):** This is the sound level that is exceeded for xx percent of the measurement period. For example, L99 is the sound level exceeded 99 percent of the measurement period. For a one hour period, the sound level is less than L99 for 36 seconds of the hour and the sound level is greater than L1 for 36 seconds of the hour. L1 represents typical maximum sound levels, L33 is approximately equal to Leq when free-flowing traffic is the dominant noise source, L50 is the median sound level, and L99 is close to the minimum sound level.

A.2 FUNDAMENTALS OF VIBRATION

Vibration is an oscillatory motion that can be described in terms of the displacement, velocity, or acceleration of the motion. One potential effect from the proposed project is an increase in vibration that is transmitted from the tracks through the ground into adjacent houses. When evaluating human response, groundborne vibration is usually expressed in terms of decibels using the RMS vibration velocity. RMS is defined as the average of the squared amplitude of the vibration signal. To avoid confusion with sound decibels, the abbreviation VdB is used for vibration decibels. All vibration decibels in this report use a decibel reference of 1 µin/sec. Vibration can also be expressed as the peak particle velocity (PPV), which is generally used to evaluate whether vibration has potential to cause damage to fragile building structures. Peak particle velocity is normally expressed in inches per second.

The potential adverse effects of groundborne vibration are as follows:

- **Perceptible Building Vibration:** This is when building occupants feel the vibration of the floor or other building surfaces. Experience has shown that the threshold of human perception is around 65 VdB and that vibration that exceeds 75 to 80 VdB may be intrusive and annoying to building occupants.
- **Rattle:** The building vibration can cause rattling of items on shelves and hanging on walls, and various different rattle and buzzing noises from windows and doors.
- **Reradiated Noise:** The vibration of room surfaces radiates sound waves that may be audible to humans. This is referred to as groundborne noise. When audible groundborne noise occurs, it sounds like a low-frequency rumble. For surface rail systems the groundborne noise is usually masked by the normal airborne noise radiated from the transit vehicle and the rails.
- **Damage to Building Structures:** Vibration from rail systems is usually one to two orders of magnitude below the most restrictive thresholds for preventing building damage. However, fragile and extremely fragile structures may be susceptible to damage if the tracks are in sufficient proximity to the structure.

Figure 9-3 shows typical RMS vibration velocity levels from rail and non-rail sources as well as the human and structure response to such levels.

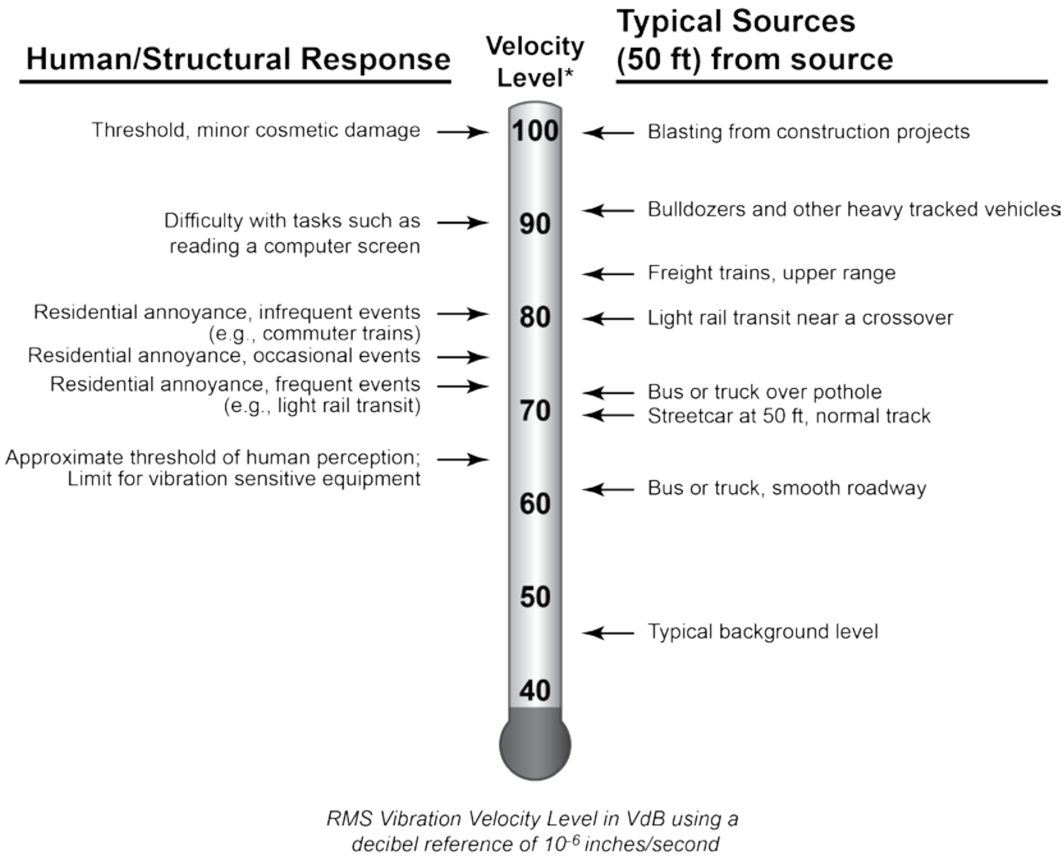

Figure 9-3: Typical RMS Vibration Velocity Levels

Often it is necessary to determine the contribution at different frequencies when evaluating vibration or noise signals. The 1/3-octave band spectrum is the most common procedure used to evaluate frequency components of acoustic signals. The term “octave” has been 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 21/3:1 (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. The FTA Guidance Manual is a good reference for additional information on transit noise and vibration and the technical terms used in this section.