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, I-5 to Medina: Bridge Replacement and HOV 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 |
| MOHAI | Museum of History and Industry |
| 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.

***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 Mitigation and Monitoring Report (the Report) is a corridor wide assessment of the potential effects during construction of the SR 520, I-5 to Medina Bridge Replacement Project and HOV 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 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 is based on the description of construction activities in the SR520, I-5 to Medina Bridge Replacement and HOV Project Construction Techniques and Activities Discipline Report Addendum and Errata, May 2011. The Report does not include the Floating Bridge and Landings area of the corridor, a separate project under construction that is assessed in a separate report, Construction Noise and Vibration Mitigation and Monitoring Plan, Evergreen Point Floating Bridge and Landings Project, July 17, 2012. The West Connection Bridge project is also assessed in a separate report, Construction Noise and Vibration Report, SR 520, West Connection Bridge Project, November 23, 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 (the Project) on the historic and non-historic properties during the construction.

The Report is also intended to provide guidance and additional information to the Design Build Contractor(s) on the noise and vibration limits of their planned means and methods of construction and location for vibration monitoring during construction. The Report will also become part of the Community Construction Mitigation Plan (CCMP) for this Project. The construction noise and vibration predictions in the Report are based on general assumptions of anticipated construction methods and approximate locations of construction activities. The noise and vibration predictions and mitigation recommendations may be revised at a later date as more detailed plans and means and methods of construction become available.

The Report includes the following elements:

- Construction activities
- Sensitive receivers affected by construction noise and vibration
- Construction noise regulations
- Vibration damage risk criteria
- Predicted construction noise levels
- Predicted construction vibration levels
- Potential mitigation measures
- Vibration monitoring during construction

Included at the end of this report in Appendix A is background information on the fundamentals of noise and vibration.

# 2 *Construction Activities*

The following sections contain brief descriptions of the major construction activities required for the different areas of the Project and the assumed construction means and methods that will be used by the Contractor. Figure 2-1 shows the general locations of those areas and activities. The construction equipment assumed for each of the activities are based on the most current means and methods available as contained in the Construction Techniques and Activities Discipline Report Addendum and Errata, May 2011, but may change or be adjusted in the future.

## 2.1 West Approach Area

In the West Approach area, the Project includes a new west approach bridge configured to be compatible with future high-capacity transit (including light rail). The new west approach bridge will be constructed in two phases: the West Approach Bridge North (WABN) running from the western shoreline in the Montlake area to the new floating bridge and the West Approach Bridge South (WABS) running south of and parallel to the WABN. Other elements of the Project include improved bridge clearance over Foster Island and the Arboretum Waterfront Trail and the removal of the existing Lake Washington Boulevard ramps. The main noise and vibration generating activities in this area for both the WABN and WABS are:

- Pile driving: Impact hammers or vibratory hammers are to be used to install temporary piles to support work bridges, install piles for the new bridge, install shaft casings, and remove piles from the existing bridge. Pile driving will occur during daytime hours only over a period of 16 non-consecutive months. A total of 2,300 piles are required in the west approach area. The work bridges requiring pile driving will be north of the existing Union Bay and west approach bridges.
- Demolition of existing west approach: A mounted hammer hoe ram is assumed to be used to demolish portions of the existing west approach to make way for the new structure.
- Demolition of existing ramps: A mounted hammer hoe ram is assumed to be used to demolish the existing Lake Washington Boulevard and R.H. Thomson Expressway ramps following the construction of the new west approach bridge.

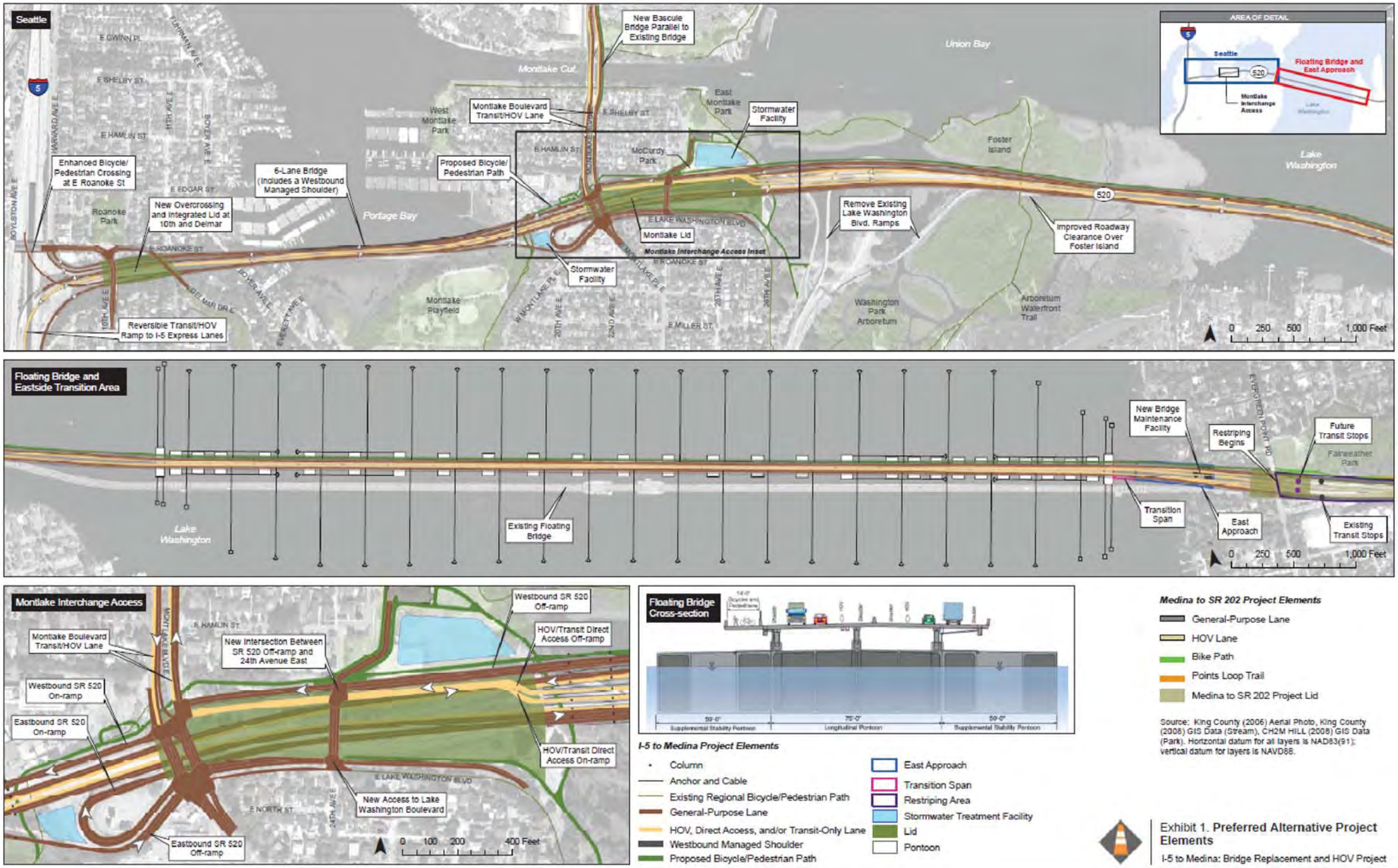


**Figure 2-1: General Locations of Construction Activities**

## 2.2 Montlake Interchange Area

In the Montlake Interchange area, the Project includes an improved urban interchange at Montlake Boulevard integrated with a 1,400 foot long lid configured for transit, pedestrian, and community connectivity. In addition, a new bascule bridge would be constructed over the Montlake Cut parallel to the existing bridge. The Montlake interchange will be rebuilt at its current location. New bridges over SR520 at Montlake Boulevard and 24th Avenue East would be constructed as part of the lid extending from Montlake Boulevard to just west of the Union Bay Shoreline. In addition, a constructed storm water treatment wetland with an outfall to Lake Washington would be built at the current Museum of History and Industry site, and would be completed towards the end of the interchange construction. However, the storm water treatment wetland will not require any impact construction activities so no vibration levels were modeled. The main noise and vibration generating construction activities in this area are:

- Demolition of the existing interchange: A mounted hammer hoe ram is assumed to be used to demolish the existing interchange to make way for the new structures.
- Demolition of the Museum of History and Industry (MOHAI) to accommodate the siting and construction of a stormwater treatment wetland.Pile driving: A vibratory hammer is assumed to be used to install piles for the new bascule bridge.
- Construction of new overcrossings and integrated lid: Sheet piles for the walls of the integrated lid will require drilling using an auger drill rig. To support construction of the lid, other pieces of equipment such as backhoes, concrete mixers, dozers, dump trucks, front end loaders, mobile cranes, and generators are all assumed to be operating within the construction area.

## 2.3 Portage Bay Bridge Area

In the Portage Bay Bridge Area, the Project includes a new six-lane Portage Bay Bridge with a 14-foot wide westbound managed shoulder. The new bridge will be built in the same location as the existing bridge. The construction of the new Portage Bay Bridge will include the construction of a work bridge, false work, and the demolition of the existing bridge. The main noise and vibration generating construction activities are:

- Pile driving: A vibratory hammer is assumed to be used to install piles to support work bridges and false work, to install piles for the new bridge, and to remove the existing piles. Pile driving will occur during daytime hours only over a period of 14 non-consecutive months. A total of 850 piles are required in the Portage Bay Bridge area.
- Demolition of existing bridge: A mounted hammer hoe ram is assumed to be used to demolish the existing Portage Bay Bridge to make way for the new structure.

## 2.4 I-5 Interchange Area

In the I-5 interchange area, the Project includes a reversible transit/HOV ramp to the I-5 express lanes, enhanced bicycle and pedestrian crossing adjacent to the East Roanoke Street bridge over I-5, and new overcrossings and an integrated lid at 10th Avenue East and Delmar Drive East. In addition, the SR 520 main line and ramps would be reconstructed in generally the same location as today from the I-5 interchange to the 10th Avenue East/Delmar Drive East lid. The main noise and vibration generating construction activities in this area are:

- Limited demolition of the existing East Roanoke Street Bridge: A mounted hammer hoe ram is assumed to be used to demolish parts of the existing bridge during construction of the enhanced bicycle and pedestrian crossing.
- Demolition of the existing SR520 mainline and ramps: A mounted hammer hoe ram is assumed to be used to demolish the existing SR520 to make way for the reconstruction.
- Construction of new overcrossings and integrated lid: Sheet piles for the walls of the integrated lid will require drilling using an auger drill rig. To support construction of the lid, other pieces of equipment such as backhoes, concrete mixers, dozers, dump trucks, front end loaders, mobile cranes, and generators are all assumed to be operating within the construction area.

# 3 *Historic Properties in the APE*

Historic properties that may be affected by the Project were identified in the Final Environmental Impact Statement (FEIS) and the Section 106 Programmatic Agreement between FHWA/WSDOT and the Washington State Historic Preservation Officer. The historic properties are often within 200 to 300 feet of the construction activities.

Table 3-1 presents the historic properties that are assessed for vibration impact in this Report. The remainder of the historic properties identified in the FEIS are greater than 500 feet from any construction activities and do not have a potential for impact. The first column in Table 3-1 is the Property ID number used in the FEIS to identify historic properties. The ID numbers are also used in Section 7 (Construction Vibration Predictions) of this Report in both the tables and graphics to refer to specific historic properties.

**Table 3-1: Historic Properties**

| Property ID | Property Name | Street Address |
|---|---|---|
| 20 | Talder House | 2352 Broadway Avenue East |
| 22 | East Miller Condominium | 904 East Miller Street |
| 23 | Sugamura House | 2408 Broadway Avenue East |
| 25 | Wicklund-Jarr House | 910 East Miller Street |
| 26 | Glover Homes | 914 East Miller Street |
| 27 | Keuss Building | 2351 10th Avenue East |
| 36 | Fire Station #22 | 901 East Roanoke St |
| 39 | Boyd House | 2422 Federal Avenue East |
| 45 | Andrew Gunby House | 1118 E Roanoke St |
| 48 | Alden Mason House | 2545 Boyer Ave East |
| 52 | Kelley House | 2518 Boyer Ave East |
| 53 | Montlake Cut | Lake Washington Ship Canal |
| 54 | Montlake Bridge | Montlake Boulevard NE over Lake Washington Ship canal |
| 55 | Seattle Yacht Club | 1807 East Hamlin Street |
| 56 | NOAA Northwest Fisheries and Science Center | 2723 Montlake Blvd NE |
| 58 | | 1893 East Hamlin Street |
| 61 | | 1896 East Hamlin Street |
| 63 | | 2815 Montlake Boulevard NE |

| | | |
|---|---|---|
| 64 | | 1897 East Shelby Street |
| 75 | | 2136 East Shelby Street |
| 76 | | 2142 East Shelby Street |
| 77 | | 2146 East Shelby Street |
| 79 | | 2158 East Shelby Street |
| 80 | Mary Houlahan House | 2159 East Shelby Street |
| 83 | | 2147 East Shelby Street |
| 90 | | 2111 East Shelby Street |
| 94 | | 2110 East Hamlin Street |
| 101 | | 2164 East Hamlin Street |
| 109 | | 2133 East Hamlin Street |
| 110 | | 2127 East Hamlin Street |
| 111 | | 2121 East Hamlin Street |
| 123 | | 2511 West Montlake Place East |
| 124 | | 2575 Montlake Place East |
| 125 | | 2501 W Montlake Place East |
| 126 | Montlake Community Center | 1618 East Calhoun Street |
| 160 | | 2600 Montlake Place East |
| 161 | | 2604 Montlake Place East |
| 162 | | 2610 Montlake Place East |
| 166 | | 2219 Lake Washington Blvd East |
| 169 | | 2231 Lake Washington Blvd East |
| 171 | | 2401 Lake Washington Blvd East |
| 175 | | 2425 Lake Washington Blvd East |
| 179 | | 2441 Lake Washington Blvd East |
| 180 | | 2445 Lake Washington Blvd East |
| 181 | | 2449 Lake Washington Blvd East |
| 184 | | 2465 Lake Washington Blvd East |
| 187 | | 2603 East Roanoke Street |
| 199 | | 2451 26th Ave East |
| 200 | Washington Park Arboretum | 2300 Arboretum Drive East |
| 200 | Foster Island | |
| 201 | Arboretum Aqueduct | |
| 203 | UW Canoe House | |
| 226 | Edgewater Condominiums | 2411 42nd Ave East |
| 432 | | 2637 Boyer Ave East |
| 433 | | 2633 Boyer Ave East |
| 434 | | 2629 Boyer Ave East |
| 437 | | 2617 Boyer Avenue East |
| 501 | | 2430 Boyer Ave East |
| 502 | | 2428 Boyer Ave East |
| 503 | | 2424 Boyer Ave East |

# 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 State of Washington noise control ordinance (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 (Ordinance 102228), Chapter 25.08, Noise Control, regulates the noise levels of construction and equipment operations (Section 25.08.425). The ordinance requires that equipment used in commercial construction activities not exceed the maximum permissible sound levels presented 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.

Levels may be exceeded between the hours of 7 a.m. and 10 p.m. on weekdays and between the hours of 9 a.m. and 10 p.m. on weekends by no more than the following dBAs for the following types of equipment:

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.

**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)** |
| Rural | 52 | 55 | 57 |
| 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, the levels in Table 4.1 are reduced by 10 dBA.

The Washington Administrative Code (WAC) 173-60-050 states: “(3) The following shall be exempt from the provisions of WAC 173-60-040, except insofar as such provisions relate to the reception of noise within Class A EDNAs between the hours of 10:00 p.m. and 7:00 a.m.: (a)

Sounds originating from the temporary construction sites as a result of construction activity." Therefore, the noise from the construction of the Project is not subject to daytime noise limits set forth in the state of Washington Administrative Code. The relevant noise criteria for the Project are the Seattle Noise Ordinance daytime noise limits shown in Table 4-1 and the noise limits for impact equipment discussed in the following section.

### *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 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 a.m. and 5 p.m. on weekdays and 9 a.m. and 5 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 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 p.m. to 7 a.m. and weekends from 9 a.m. to 10 p.m.) cannot meet the maximum permissible levels established by Section 25.08.410 of the Noise Ordinance (Table 4-1), a noise variance is required. The Project will include nighttime construction activities; however, the type and extent of nighttime construction activities will not be determined until the means and methods of construction are available.

# 5 *Construction Vibration Thresholds*

Construction vibration can 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 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] and 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 such as movement of hanging objects, and time of day (e.g., late at night) all play some role in the response of individuals. 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, which 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.

Numerous other studies have been conducted to characterize the human response to vibration. These studies have concluded that steady-state (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 SR 520 Project since the

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[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.

highest 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.

The results in Table 5-1and Table 5-2 suggest that the thresholds for perception and annoyance are higher for transient vibration that occurs over a short period of time than for continuous vibration.

## 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 that were used during the environmental impact assessment phase to identify problem locations that must be addressed during final design and monitored during construction; not the limit at which damage will occur. 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 tables) 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.

# 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

[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.

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 following sections present the predictions of noise levels at the properties closest to the construction activities in each of the construction areas identified in Section 2.0. The noise impact thresholds applied in this analysis are:

- Impact equipment (impact or vibratory pile drivers, mounted hammer hoe rams): 90 dBA
- General construction activities: 80 dBA (based on Table 4-1 assuming residential receivers with a residential noise source)

If the predicted noise level at any property exceeds the applicable threshold, mitigation measures are recommended for the offending construction activity in Section 7.4.

### *West Approach Area*

The major noise generating equipment assumed to be used in the West Approach area are the vibratory pile driver, impact pile driver and the mounted hammer hoe ram. The vibratory pile driver and impact pile driver are assumed to be used to install piles for the temporary work bridge, to remove piles from the existing west approach, to install shaft casings and to install piles for the new west approach. A mounted hammer hoe ram is assumed to be used to demolish the existing west approach structure and the existing Lake Washington Boulevard ramps.

The worst-case predicted noise levels at the properties closest to construction are presented in Table 6-2. Note that the vibratory pile driver and impact pile driver have the same reference noise level, so the predicted noise level is the same regardless of the type of pile driving. Predicted noise contours are shown in Figure 6-1 through Figure 6-4. The closest properties listed in the table are labeled as *R1* in the figures. For pile driving, the worst-case predictions are provided for the west-most pile location and east-most pile location. For demolition, only the eastern end of the West Approach is modeled. The demolition of the western end of the west approach is included in the Montlake Interchange area analysis.

The predicted levels do not exceed the applicable noise threshold (90 dBA) at the closest properties. Therefore, noise mitigation measures do not need to be implemented in the western approach area.

**Table 6-2: Predicted Noise Levels in the West Approach Area**

| Construction Activity | Equipment | Closest Property | Distance to Construction | Predicted Noise at Receiver (Lmax dBA) |
|---|---|---|---|---|
| West approach pile driving/pile removal (west end) | Vibratory Pile Driver / Impact Pile Driver | 2459 Lake Washington Boulevard | 300 ft | 83 dBA |
| West approach pile driving/pile removal (east end) | Vibratory Pile Driver / Impact Pile Driver | 2411 42nd Ave East (Edgewater Condominiums) | 250 ft | 89 dBA |
| Existing west approach bridge demolition | Mounted Hammer Hoe Ram | 2411 42nd Ave East (Edgewater Condominiums) | 250 ft | 84 dBA |
| Existing Lake Washington Ramps demolition | Mounted Hammer Hoe Ram | 2531 Lake Washington Boulevard | 290 ft | 79 dBA |

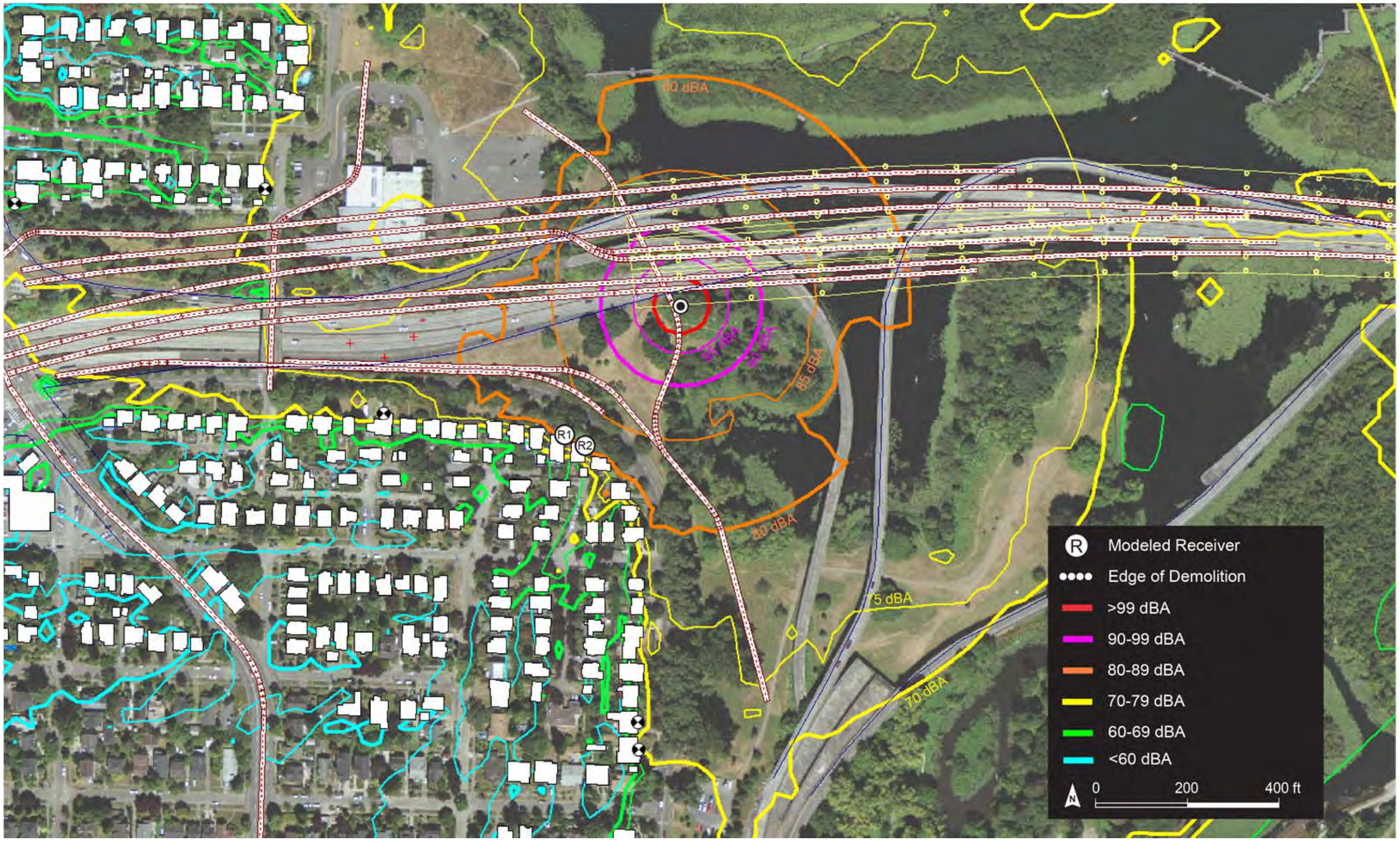


**Figure 6-1: Predicted Noise Contours for West Approach Area Pile Driving, West End**


**Figure 6-2: Predicted Noise Contours for West Approach Area Pile Driving, East End**

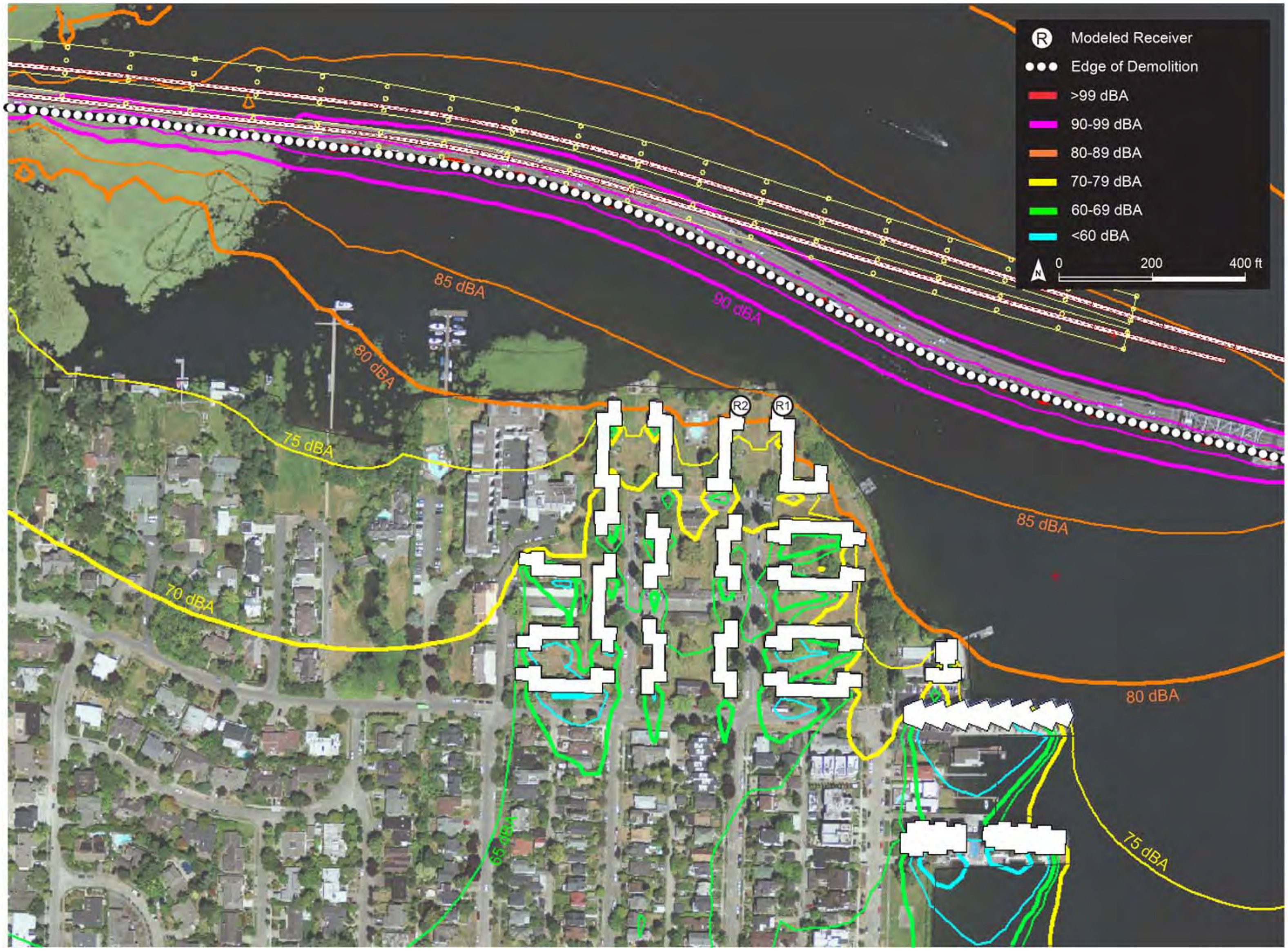


**Figure 6-3: Predicted Noise Contours for West Approach Area Demolition**

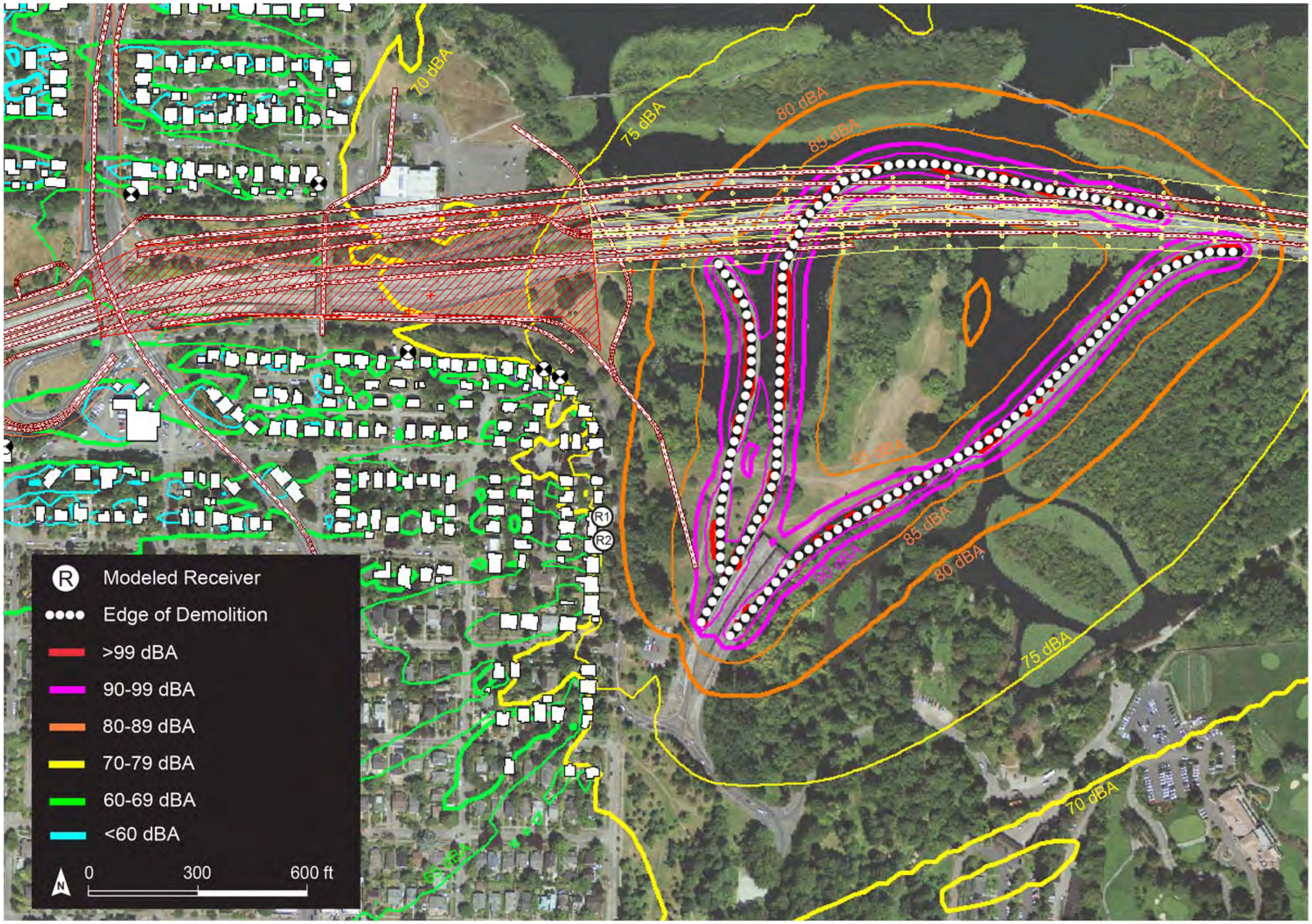


**Figure 6-4: Predicted Noise Contours for Demolition of Lake Washington Boulevard Ramps**

### *Montlake Interchange Area*

The major noise generating impact equipment assumed to be used in the Montlake Interchange area are the vibratory pile driver and the mounted hammer hoe ram. The vibratory pile driver is assumed to be used to install piles for the new Bascule Bridge over the Montlake Cut. The mounted hammer hoe ram is assumed to be used to demolish the existing interchange structure. The demolition of the MOHAI includes an excavator and will not require any impact equipment. The construction of the lid will not require any impact equipment. The noise model for lid construction includes the following pieces of equipment operating simultaneously to represent a worst-case construction noise scenario: auger drill rig, backhoe, concrete mixer truck, dozer, dump truck, front end loader, generator, and mobile crane.

The worst-case predicted noise levels at the properties closest to construction are presented in Table 6-3. Predicted noise contours are shown in Figure 6-5 through Figure 6-8. The closest property listed in the table is labeled as *R1* in the figures.

The predicted noise level for demolition of the existing interchange exceeds the threshold for impact equipment (90 dBA) and the predicted noise level for lid construction exceeds the threshold for general construction activities (80 dBA). Mitigation measures may be required during demolition and lid construction to ensure noise levels will not be exceeded.

**Table 6-3: Predicted Noise Levels in Montlake Interchange Area**

| Construction Activity | Equipment | Closest Property | Distance to Construction | Predicted Noise at Receiver (Lmax dBA) |
|---|---|---|---|---|
| Bascule bridge pile driving (south end) | Vibratory Pile Driver | 2112 E Shelby Street | 140 ft | 86 dBA |
| Demolition of existing interchange | Mounted Hammer Hoe Ram | 2734 Montlake Boulevard East | 30 ft | ***92 dBA*** |
| Demolition of MOHAI Building | Excavator | 2151 East Hamlin Street | 130 ft | 71 dBA |
| Lid construction | Various Equipment | 2151 East Hamlin Street | 100 ft | ***81 dBA*** |


**Figure 6-5: Predicted Noise Contours for Bascule Bridge Pile Driving**

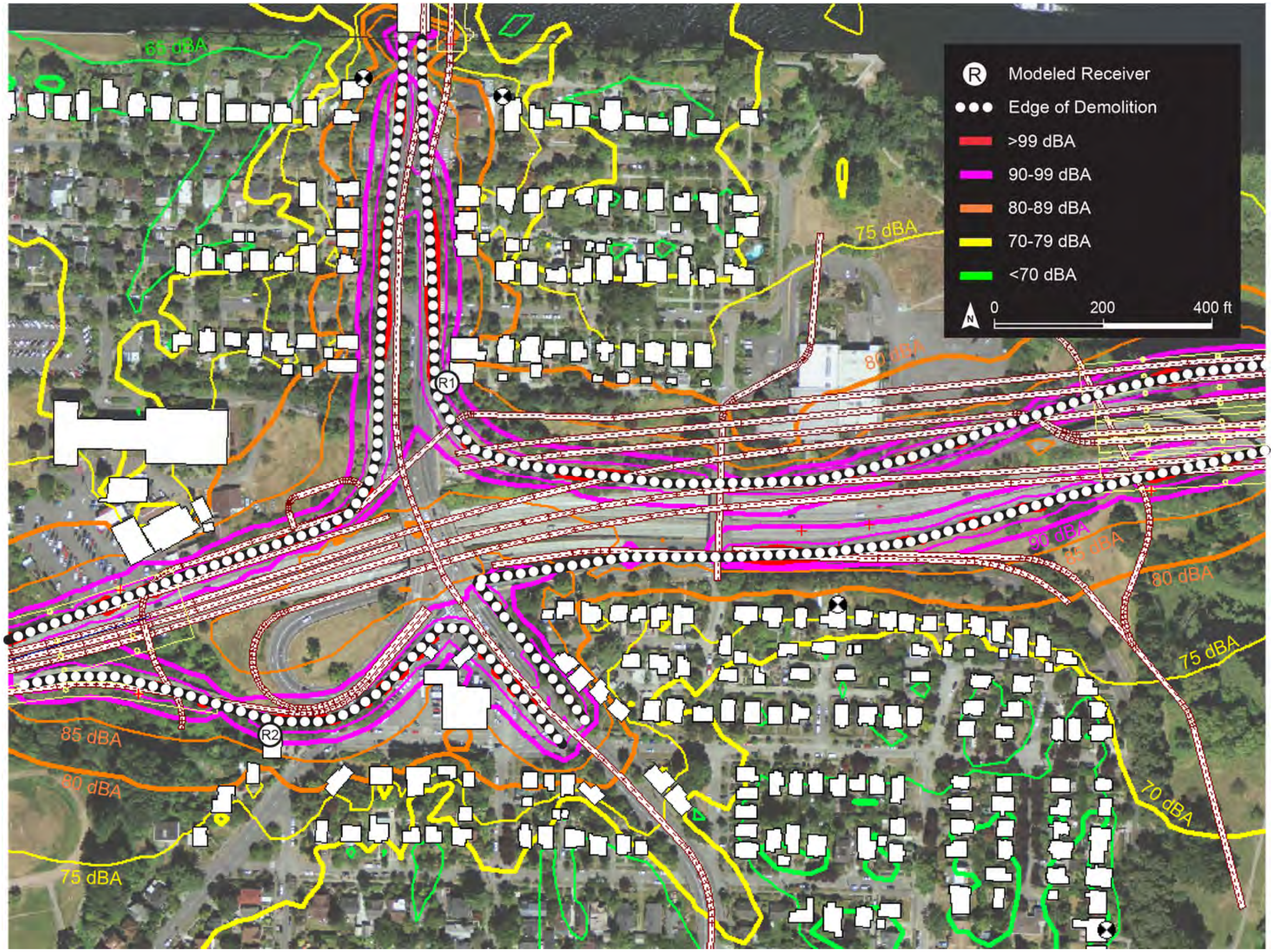


**Figure 6-6: Predicted Noise Contours for Demolition of Existing Montlake Interchange**

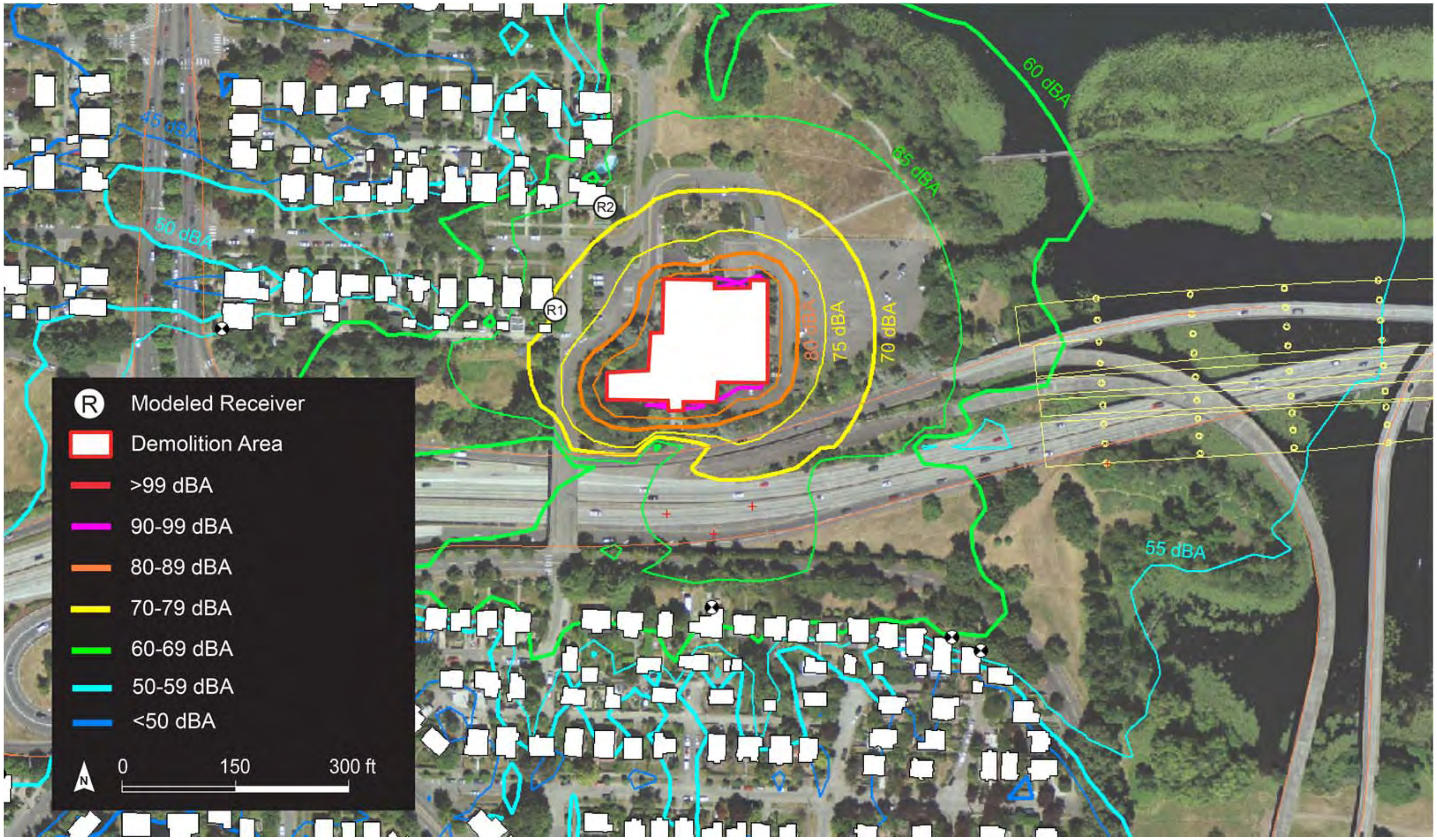


**Figure 6-7: Predicted Noise Contours for Demolition of Museum of History and Industry (MOHAI)**


**Figure 6-8: Predicted Noise Contours for Montlake Interchange Lid Construction**

### *Portage Bay Bridge Area*

The major noise generating equipment assumed to be used in the Portage Bay Bridge area is the vibratory pile driver and the mounted hammer hoe ram. The vibratory pile driver is assumed to be used to install piles for the temporary work bridge, to install piles for the new Portage Bay Bridge, and to remove the piles from the existing bridge. The mounted hammer hoe ram is assumed to be used to demolish the existing bridge.

The worst-case predicted noise levels at the properties closest to construction are presented in Table 6-4. Predicted noise contours are shown in Figure 6-9 through Figure 6-11. The closest properties listed in the table are labeled as *R1* in the figures. For pile driving, the worst-case predictions are provided for the west-most pile location and east-most pile location.

The predicted noise levels for pile driving exceed the City of Seattle noise threshold for impact equipment (90 dBA). Mitigation measures may be required during pile driving to ensure noise level limits will not be exceeded.

**Table 6-4: Predicted Noise Levels in the Portage Bay Bridge Area**

| Construction Activity | Equipment | Closest Property | Distance to Construction | Predicted Noise at Receiver (Lmax dBA) |
|---|---|---|---|---|
| Portage Bay work bridge pile driving (west end) | Vibratory Pile Driver | 2608 Boyer Avenue East (Queen City Yacht Club) | 110 ft | ***95 dBA*** |
| Portage Bay work bridge pile driving (east end) | Vibratory Pile Driver | 2723 Montlake Boulevard NE (NOAA Northwest Fisheries and Science Center) | 55 ft | ***102 dBA*** |
| Existing Portage Bay Bridge demolition | Mounted Hammer Hoe Ram | 2575 West Montlake Place East (residence) | 30 ft | 85 dBA |

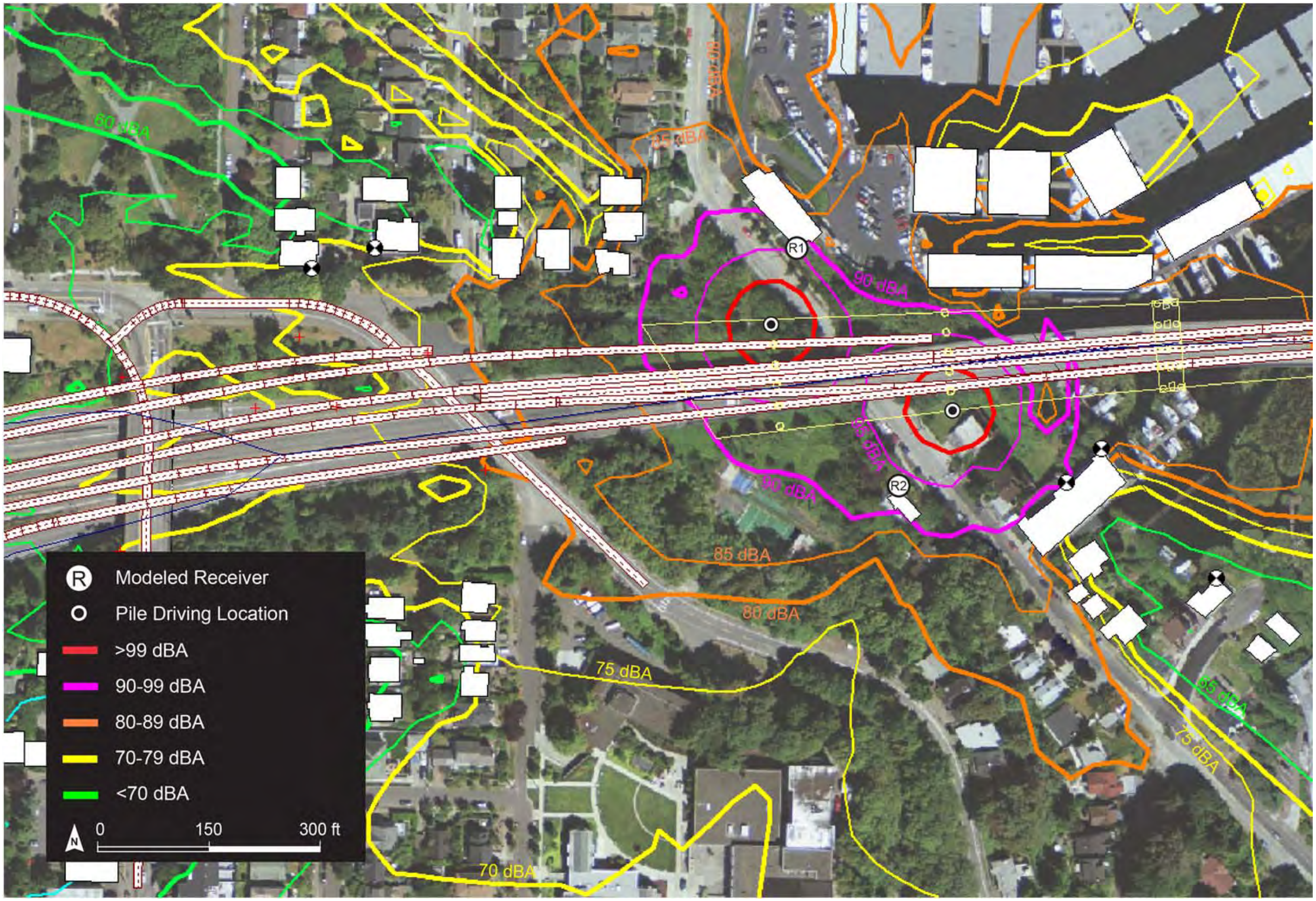


**Figure 6-9: Predicted Noise Contours for Portage Bay Bridge Pile Driving, West End**

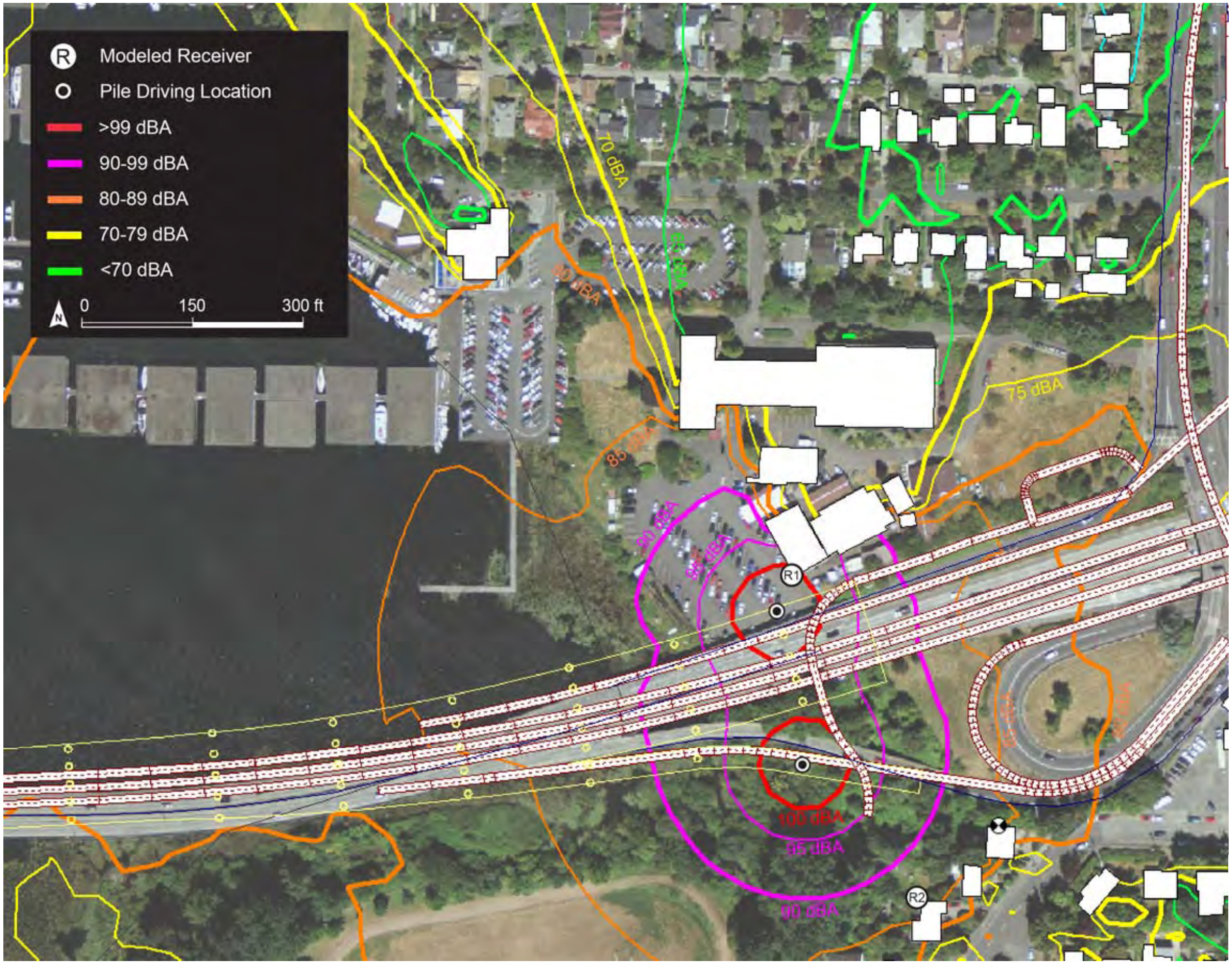


**Figure 6-10: Predicted Noise Levels for Portage Bay Bridge Pile Driving, East End**

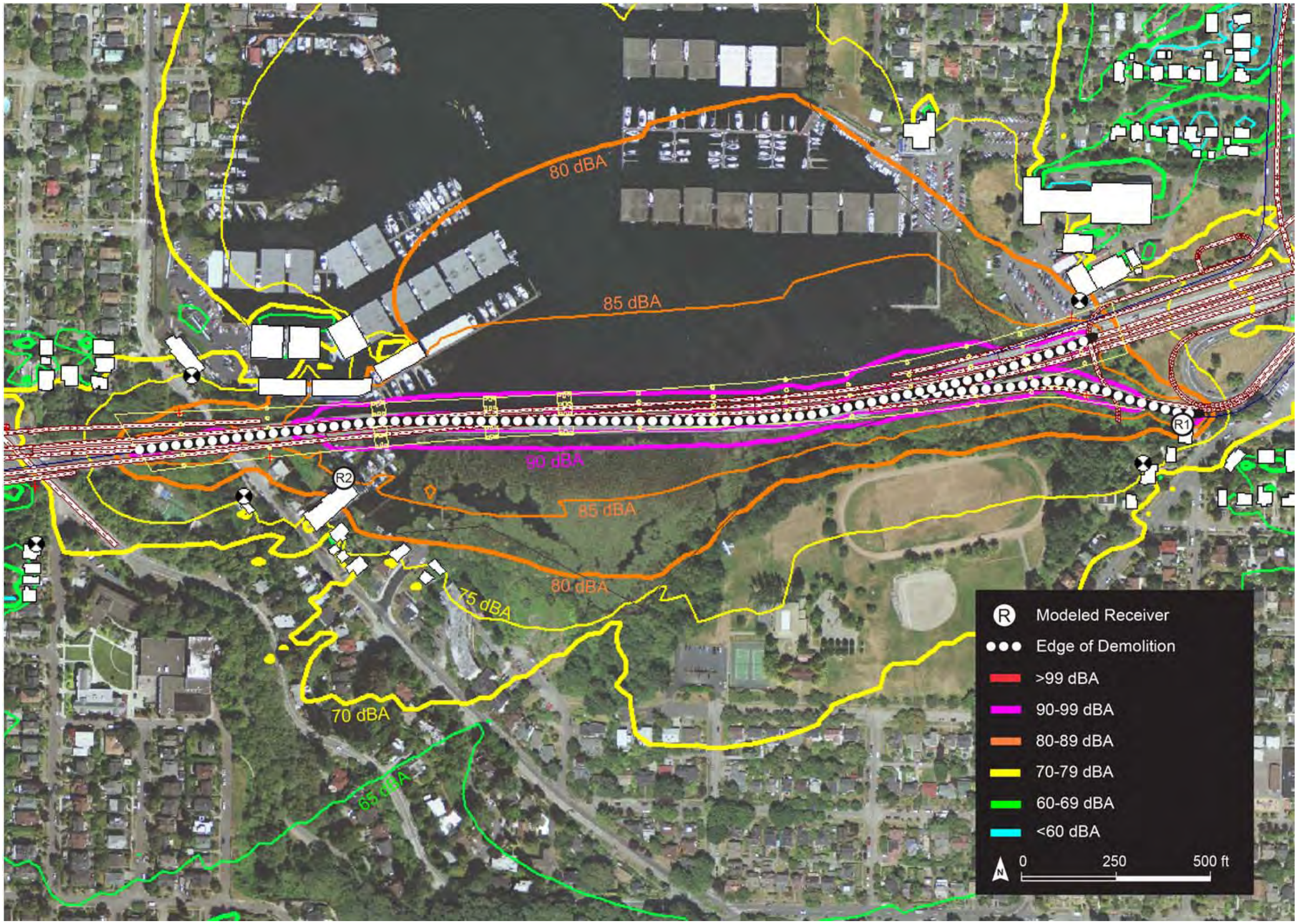


**Figure 6-11: Predicted Noise Levels for Portage Bay Bridge Demolition**

### *I-5 Interchange Area*

The major noise generating impact equipment assumed to be used in the I-5 Interchange area is the mounted hammer hoe ram which is assumed to be used to demolish the existing SR 520 mainline and ramps and for limited demolition of the existing Roanoke Street Bridge. The construction of the lid will not require any impact equipment. The noise model for lid construction includes the following pieces of equipment operating simultaneously to represent a worst-case construction noise scenario: auger drill rig, backhoe, concrete mixer truck, dozer, dump truck, front end loader, generator, and mobile crane. This analysis is intended to be a worst case scenario. During construction it is not likely that all equipment will be operating at the same time.

The worst-case predicted noise levels at the properties closest to construction are presented in Table 6-5. Predicted noise contours are shown in Figure 6-12 through Figure 6-14. The closest properties listed in the table are labeled as *R1* in the figures.

The predicted noise levels for demolition of the existing SR 520 mainline and ramps exceed the applicable noise threshold for impact equipment (90 dBA) and the predicted noise level for lid construction exceeds the threshold for general construction activities in a residential area (80 dBA). Mitigation measures may be required during demolition and during lid construction to ensure noise levels will not be exceeded.

**Table 6-5: Predicted Noise Levels in the I-5 Interchange Area**

| Construction Activity | Equipment | Closest Property | Distance to Construction | Predicted Noise at Receiver (Lmax dBA) |
|---|---|---|---|---|
| Limited demolition of existing Roanoke Street Bridge | Mounted Hammer Hoe Ram | 2500 Franklin Avenue East (School) | 80 ft | 80 dBA |
| Demolition of existing SR520 mainline and ramps | Mounted Hammer Hoe Ram | 811 E Roanoke Street (Washington State Patrol Building) | 30 ft | ***97 dBA*** |
| Lid construction | Various Equipment | 1004 E Roanoke Street | 75 ft | ***85 dBA*** |

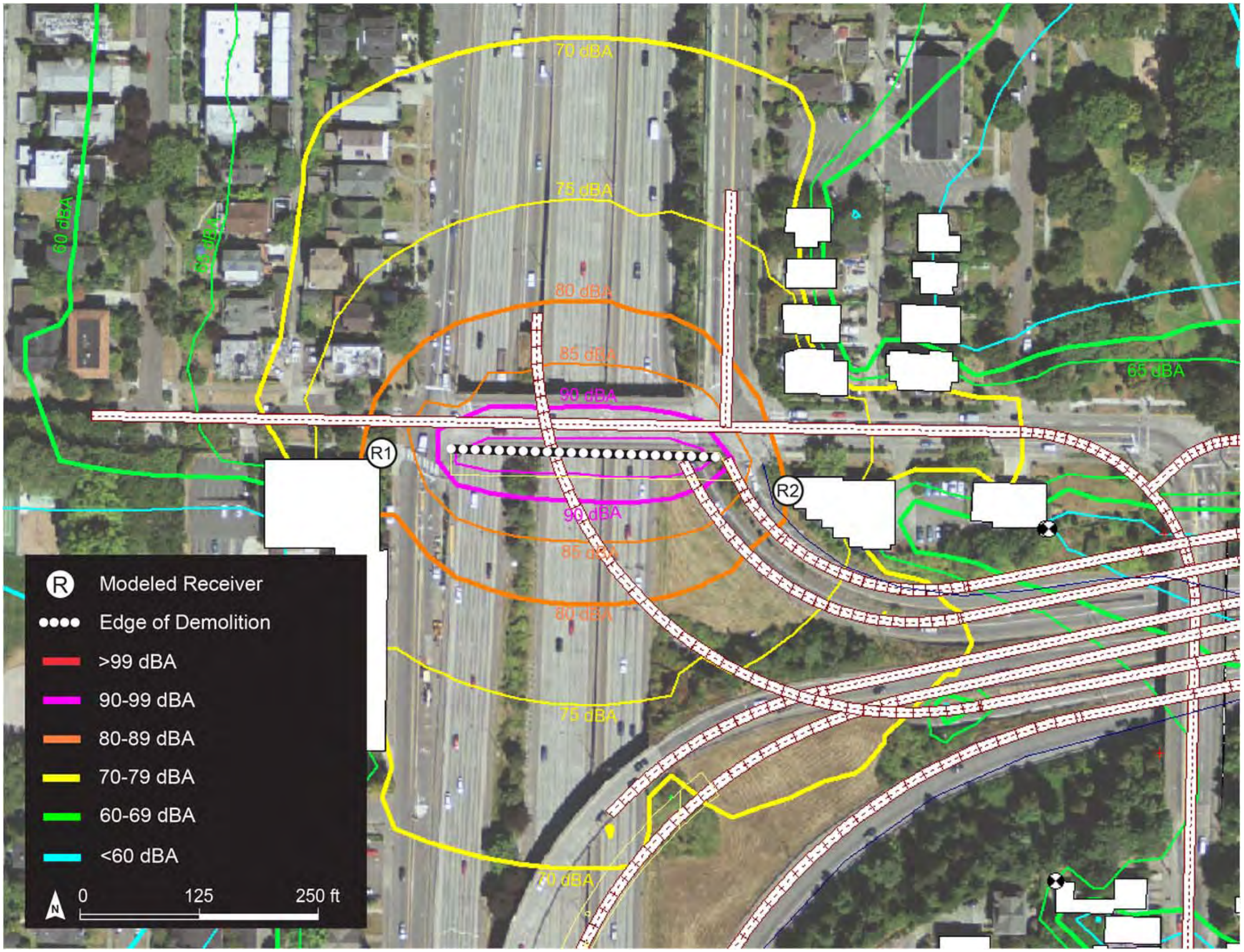


**Figure 6-12: Predicted Noise Contours for Roanoke Street Bridge Limited Demolition**

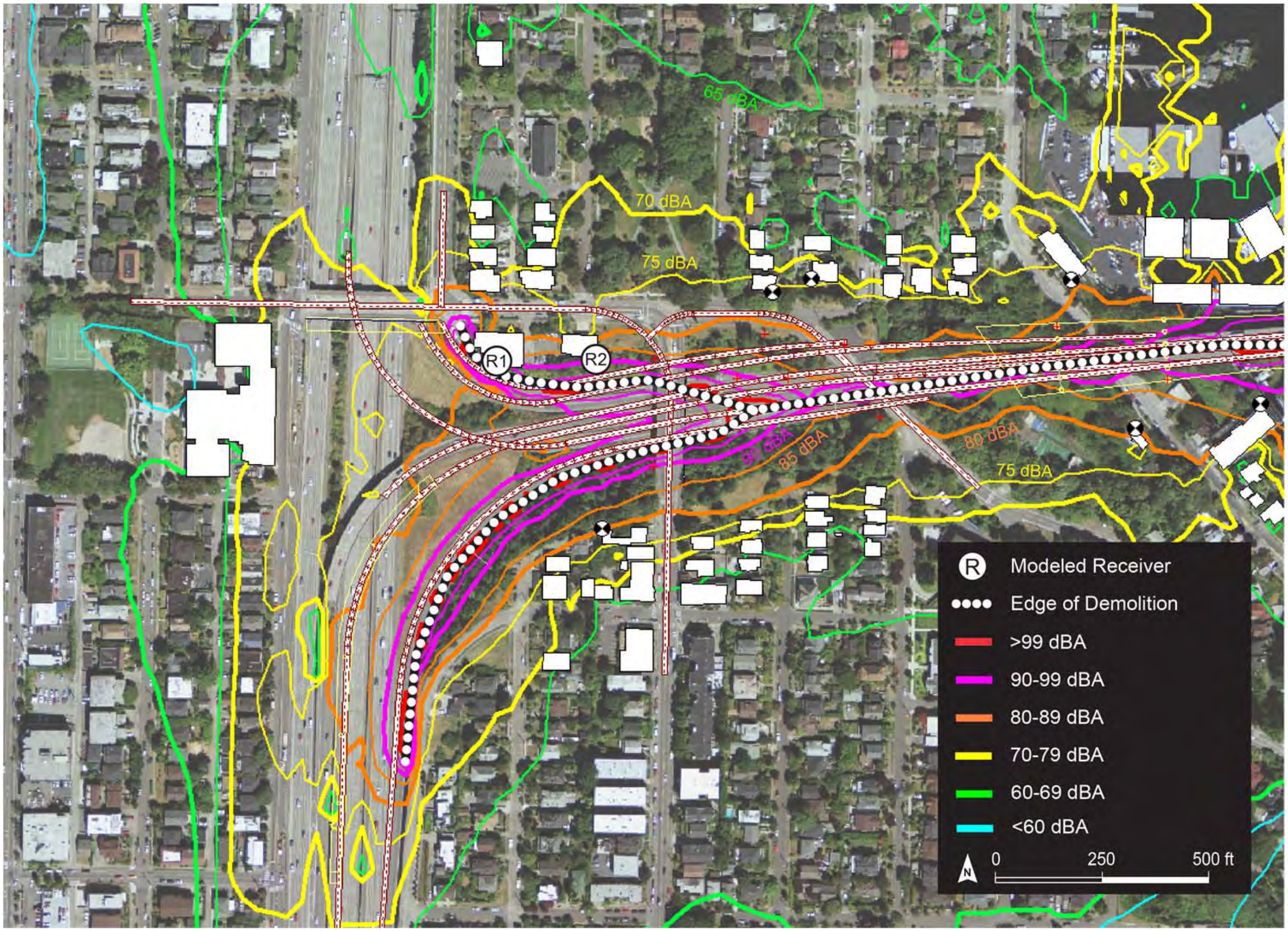


**Figure 6-13: Predicted Noise Contours for I-5 Interchange Area SR 520 Demolition**

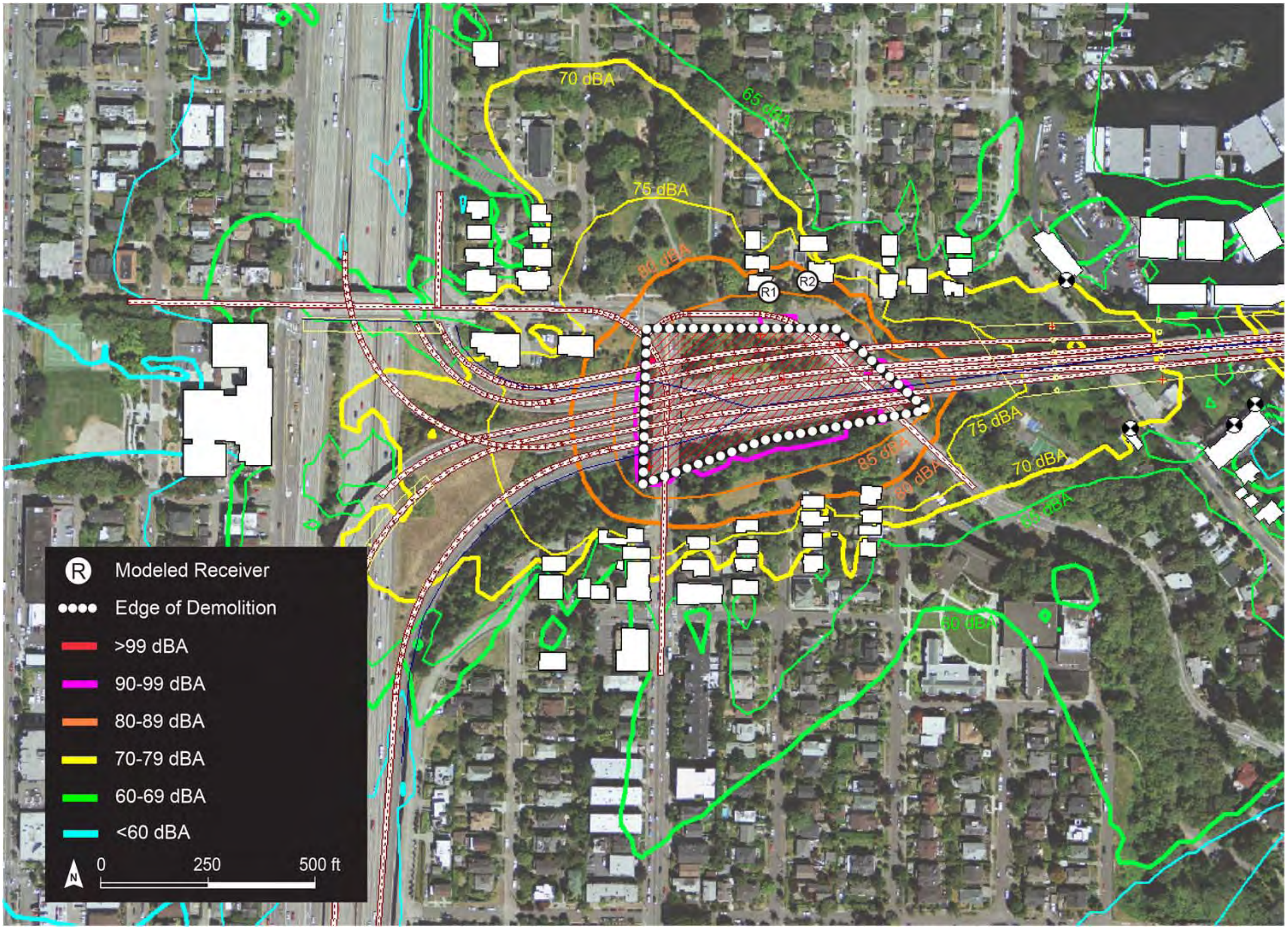


**Figure 6-14: Predicted Noise Contours for I-5 Interchange Lid Construction**

# 7 *Construction Vibration Predictions*

## 7.1 Vibration Prediction Methodology

For this study, the FTA analytical/empirical vibration prediction model was used to estimate the vibration levels that might propagate from the construction equipment to the vibration sensitive locations. The vibration model is 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[1]. 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.

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[1] 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 sections present 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 vibration criteria that are recommended by this Report to avoid or limit damage risk to the properties that would be affected during construction are:

- 0.12 inches/second PPV for historic properties
- 0.50 inches/second PPV for non-historic properties

If these limits are exceeded during construction, there is a risk of cosmetic damage and, at higher levels, structural damage to buildings. It is recommended that Contractor, being aware of these damage risk limits for historic and non-historic properties, set their vibration monitors to provide an alert when 0.12 inches/second PPV is exceeded for historic properties and 0.50 inches/second PPV is exceeded for non-historic properties. If an exceedance occurs the Contractor should immediately contact the occupants of the nearest historic property to check on any potential damage that may have occurred.

Table 7-2 presents the distance beyond which the damage risk criteria would not be exceeded for the major vibration generating pieces of equipment likely to be used for the Project. Most of the equipment, with the exception of pile drivers and hoe rams, can be operated without risk of damage at distances of 53 feet or greater from historic buildings or at distance of 15 feet or greater from non-historic buildings. The exceptions are the mounted hammer hoe ram, impact pile driver, and vibratory pile driver.

**Table 7-2: Distance to Construction Vibration Impact Thresholds**

| Equipment | Reference PPV (in/sec) at 100 ft | Distance to Impact Threshold of 0.50 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 | 3 ft | 11 ft |
| Front End Loader | 0.011 | 4 ft | 12 ft |
| Impact Pile Driver | 0.20 | 44 ft | 160 ft |
| Jackhammer | 0.003 | 1 ft | 4 ft |
| Mounted Hammer Hoe Ram | 0.18975 | 42 ft | 152 ft |
| Vibratory Pile Driver | 0.14 | 32 ft | 115 ft |
| Vibratory Roller (Large) | 0.059 | 15 ft | 53 ft |
| Vibratory Roller (Small) | 0.022 | 6 ft | 22 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'.

### *West Approach Area*

The major vibration generating equipment assumed to be used in the West Approach area is the vibratory pile driver and the mounted hammer hoe ram. The vibratory pile driver is assumed to be used to install piles for the temporary work bridge, to remove piles from the existing west approach, and to install piles for the new west approach. A mounted hammer hoe ram is assumed to be used to demolish the existing west approach structure and the existing Lake Washington Boulevard ramps.

The worst-case predicted vibration levels at the properties closest to construction are presented in Table 7-3. The predicted vibration levels for historic properties near construction activities are presented in Table 7-6. Predicted vibration contours are shown in Figure 7-1 through Figure 7-3. For pile driving, the worst-case predictions are provided for the west-most pile location and east-most pile location. For demolition, only the eastern end of the west approach is modeled. The demolition of the western end of the West Approach is included in the Montlake Interchange area analysis.

The predicted levels do not exceed the damage risk threshold (PPV of 0.5 in/sec) at any of the closest non-historic properties. The predicted levels also do not exceed the damage risk threshold (PPV of 0.12 in/sec) at any of the nearby historic properties. Therefore, vibration mitigation measures do not need to be implemented in the West Approach area. However, at this level the construction vibration will be distinctly perceptible to the nearest residences, which may result in some complaints.

**Table 7-3: Predicted Construction Vibration Levels at Closest Properties, West Approach Area**

| Construction Activity | Equipment | Closest Property | Distance to Construction | Predicted PPV at Receiver |
|---|---|---|---|---|
| West approach pile driving/pile removal (west end) | Vibratory Pile Driver | 2459 Lake Washington Boulevard | 300 ft | 0.042 |
| West approach pile driving/pile removal (east end) | Vibratory Pile Driver | 2411 42nd Ave East (Edgewater Condominiums) | 250 ft | 0.052 |
| Existing west approach bridge demolition | Mounted Hammer Hoe Ram | 2411 42nd Ave East (Edgewater Condominiums) | 250 ft | 0.069 |
| Existing Lake Washington Ramps demolition | Mounted Hammer Hoe Ram | 2451 26th Avenue East (Historic Property ID 199) | 250 ft | 0.069 |

**Table 7-4: Predicted Construction Vibration Levels at Historic Properties, West Approach Area**

| Construction Activity | Equipment | Historic Property ID[1] | Distance to Construction | Predicted PPV (in/sec) |
|---|---|---|---|---|
| West approach pile driving/pile removal (west end) | Vibratory Pile Driver | 171 | 760 ft | 0.015 |
| | | 175 | 600 ft | 0.020 |
| | | 179 | 370 ft | 0.033 |
| | | 180 | 340 ft | 0.036 |
| | | 181 | 320 ft | 0.039 |
| | | 184 | 320 ft | 0.039 |
| | | 187 | 480 ft | 0.025 |
| West approach pile driving/pile removal (east end) | Vibratory Pile Driver | 226 | 250 ft | 0.051 |
| Existing west approach bridge demolition | Mounted Hammer Hoe Ram | 226 | 250 ft | 0.069 |
| Existing Lake Washington ramps demolition | Mounted Hammer Hoe Ram | 187 | 350 ft | 0.048 |
| | | 199 | 250 ft | 0.069 |
| | | 200 | 930 ft | 0.016 |
| | | 201 | 700 ft | 0.022 |

[1] The locations of the historic properties corresponding to their ID number are shown in Table 3-1.


**Figure 7-1: Predicted Vibration Contours for West Approach Pile Driving, West End**


**Figure 7-2: Predicted Vibration Contours for West Approach Pile Driving, East End**


**Figure 7-3: Predicted Vibration Contours for Existing West Approach Bridge Demolition**


**Figure 7-4: Predicted Vibration Contours for Demolition of Existing Lake Washington Ramps in West Approach Area**

### *Montlake Interchange Area*

The major vibration generating equipment assumed to be used in the Montlake interchange area are the vibratory pile driver, mounted hammer hoe ram, and auger drill rig. The vibratory pile driver is assumed to be used to install piles for the new bascule bridge over the Montlake Cut. The mounted hammer hoe ram is assumed to be used to demolish the existing interchange structure. The auger drill rig is assumed to be used to drill sheet piles for the construction of the lid.

The worst-case predicted vibration levels at the properties closest to each construction activity are presented in Table 7-5

Table 7-5. The predicted vibration levels for historic properties near construction activities are presented in Table 7-6. Predictions that exceed the appropriate impact threshold are shown in bold and italic font. Predicted vibration contours are shown in Figure 7-5 through Figure 7-8.

The predicted vibration levels do not exceed the applicable damage risk threshold at the closest non-historic or historic properties during pile driving for the bascule bridge. Vibration mitigation measures do not need to be implemented during pile driving. However, at this level the construction vibration will be distinctly perceptible to the nearest residents and may result in complaints.

The predicted levels do exceed the thresholds during demolition at both the closest historic properties and non-historic properties. Figure 7-6 graphically shows the vibration contours at 150 ft where the predicted level is equivalent to the threshold for historic buildings (PPV 0.12 in/sec). Potential for vibration impact is predicted at all historic properties within this contour. Mitigation measures should be implemented to ensure that vibration levels do not exceed the damage risk threshold during demolition. It should also be noted that this level of construction vibration will be strongly perceptible to residents and could result in complaints.

The predicted vibration levels do not exceed the damage risk thresholds at any properties during drilling for sheet piles. Vibration mitigation measures do not need to be implemented during drilling. The predicted vibration levels during sheet piling may be barely perceptible to residents.

### Table 7-5: Predicted Construction Vibration Levels at Nearest Properties, Montlake Interchange Area

| Construction Activity | Equipment | Closest Property | Distance to Construction | Predicted PPV at Receiver |
|---|---|---|---|---|
| Bascule bridge pile driving (north end) | Vibratory Pile Driver | 3270 15th Avenue NE (UW Department of Genome Sciences) | 220 ft | 0.059 |
| Bascule bridge pile driving (south end) | Vibratory Pile Driver | 2908 Montlake Boulevard East | 140 ft | 0.097 |
| Demolition of existing interchange | Mounted Hammer Hoe Ram | 2575 W Montlake Place East (several properties at this distance) | 30 ft | ***0.713*** |
| Demolition of MOHAI | Excavator | 2151 East Hamlin Street | 130 ft | 0.008 |
| Drilling to install sheet piles | Auger Drill Rig | 2215 Lake Washington Boulevard East | 80 ft | 0.014 |

### Table 7-6: Predicted Construction Vibration Levels at Historic Properties, Montlake Interchange Area

| Construction Activity | Equipment | Historic Property ID | Distance to Construction | Predicted PPV (in/sec) |
|---|---|---|---|---|
| Bascule bridge pile driving (north end) | Vibratory Pile Driver | 203 | 1000 ft | 0.011 |
| Bascule bridge pile driving (south end) | Vibratory Pile Driver | 55 | 1160 | 0.009 |
| | | 56 | 860 | 0.013 |
| | | 58 | 650 | 0.018 |
| | | 61 | 440 | 0.027 |
| | | 63 | 340 | 0.036 |
| | | 64 | 300 | 0.042 |
| | | 75 | 340 | 0.036 |
| | | 76 | 390 | 0.031 |
| | | 77 | 420 | 0.029 |
| | | 79 | 550 | 0.021 |
| | | 80 | 600 | 0.020 |
| | | 83 | 540 | 0.022 |
| | | 90 | 270 | 0.047 |
| | | 94 | 370 | 0.033 |
| | | 101 | 550 | 0.021 |
| | | 109 | 620 | 0.019 |
| | | 110 | 610 | 0.019 |
| | | 111 | 590 | 0.020 |
| Demolition of existing interchange | Mounted Hammer Hoe Ram | ***56*** | ***50 ft*** | ***0.407*** |
| | | ***58*** | ***35 ft*** | ***0.602*** |
| | | ***61*** | ***40 ft*** | ***0.520*** |
| | | ***63*** | ***35 ft*** | ***0.602*** |
| | | ***64*** | ***40 ft*** | ***0.520*** |
| | | 75 | 360 ft | 0.046 |

| | | | | |
|---|---|---|---|---|
| | | 76 | 405 ft | 0.041 |
| | | 77 | 455 ft | 0.036 |
| | | 79 | 620 ft | 0.026 |
| | | 80 | 590 ft | 0.027 |
| | | 83 | 480 ft | 0.034 |
| | | ***90*** | ***120 ft*** | ***0.155*** |
| | | ***94*** | ***120 ft*** | ***0.155*** |
| | | 101 | 490 ft | 0.033 |
| | | 109 | 220 ft | 0.080 |
| | | 110 | 210 ft | 0.084 |
| | | 11 | 210 ft | 0.084 |
| | | 123 | 455 ft | 0.036 |
| | | 125 | 550 ft | 0.029 |
| | | ***160*** | ***50 ft*** | ***0.407*** |
| | | ***161*** | ***50 ft*** | ***0.407*** |
| | | ***162*** | ***45 ft*** | ***0.457*** |
| | | ***166*** | ***100 ft*** | ***0.190*** |
| | | ***169*** | ***95 ft*** | ***0.201*** |
| | | ***171*** | ***100 ft*** | ***0.190*** |
| | | ***175*** | ***110 ft*** | ***0.171*** |
| | | ***179*** | ***150 ft*** | ***0.121*** |
| | | 180 | 165 ft | 0.109 |
| | | 181 | 195 ft | 0.091 |
| | | 184 | 280 ft | 0.061 |
| | | 187 | 450 ft | 0.036 |
| Drilling to install sheet piles | Auger drill rig | 56 | 350 ft | 0.003 |
| | | 58 | 325 ft | 0.003 |
| | | 109 | 265 ft | 0.004 |
| | | 110 | 260 ft | 0.004 |
| | | 111 | 265 ft | 0.004 |
| | | 160 | 280 ft | 0.004 |
| | | 161 | 240 ft | 0.004 |
| | | 162 | 210ft | 0.005 |
| | | 166 | 90 ft | 0.012 |
| | | 169 | 90 ft | 0.012 |
| | | 171 | 90ft | 0.012 |
| | | 175 | 90 ft | 0.012 |
| | | 179 | 90 ft | 0.012 |
| | | 180 | 120 ft | 0.009 |
| | | 181 | 120 ft | 0.009 |
| | | 184 | 190 ft | 0.005 |
| | | 187 | 340 ft | 0.003 |

[1] The locations of the historic properties corresponding to their ID number are shown in Table 3-1.

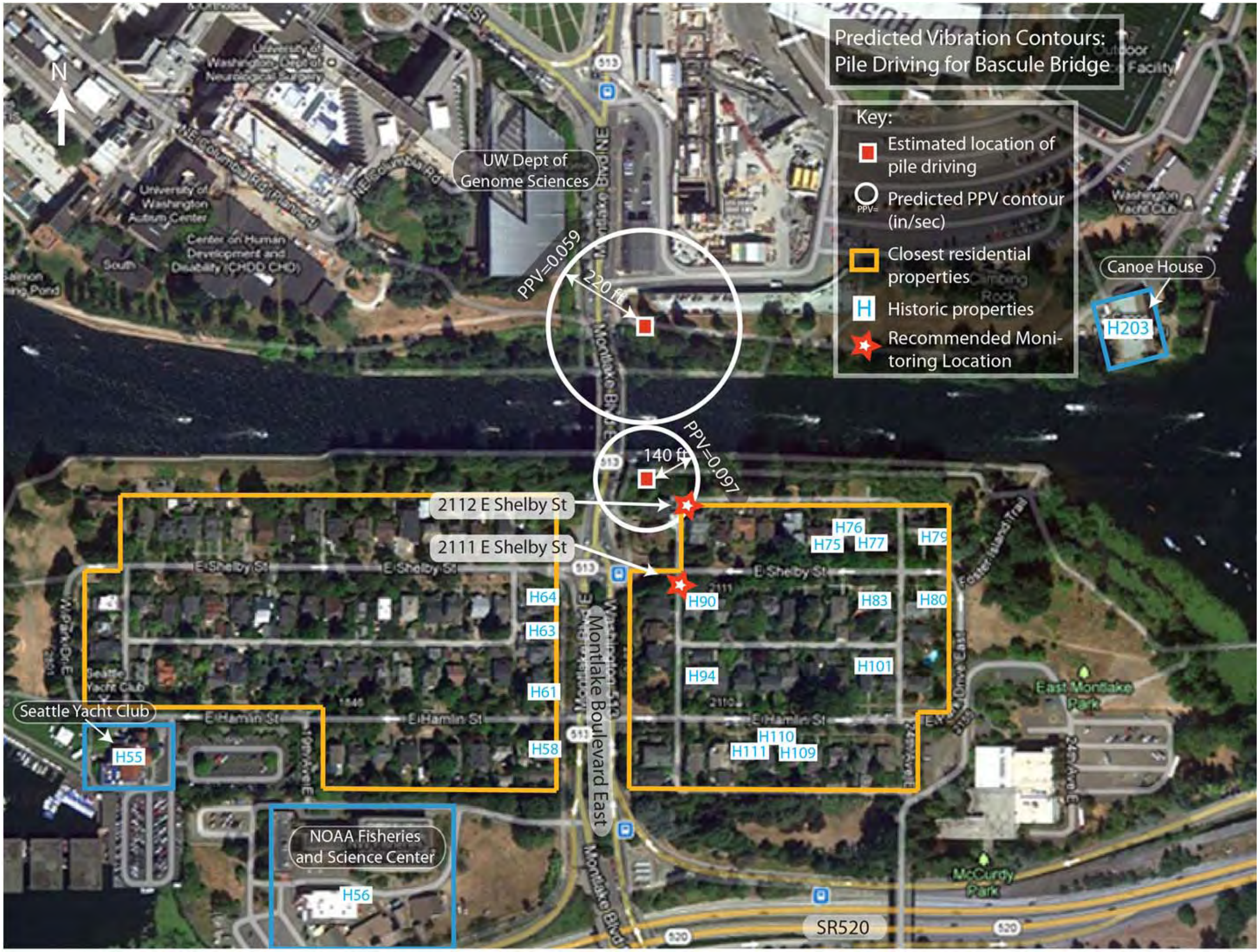


**Figure 7-5: Predicted Vibration Contours for Pile Driving at Bascule Bridge, Montlake Interchange Area**

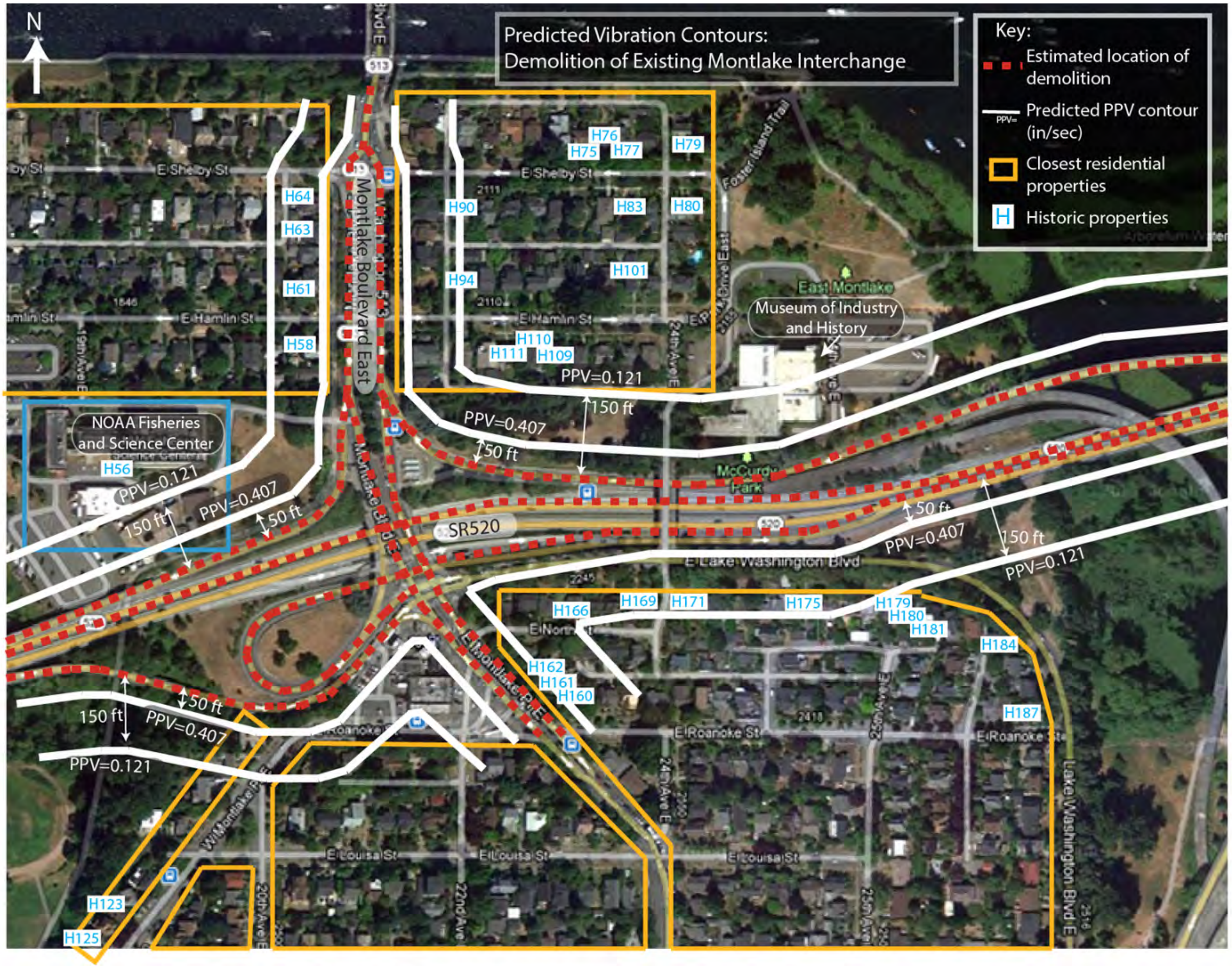


**Figure 7-6: Predicted Vibration Contours for Demolition of Existing Interchange, Montlake Interchange Area**


**Figure 7-7: Predicted Vibration Contours for Demolition of Museum of History and Industry (MOHAI)**


**Figure 7-8: Predicted Vibration Contours for Drilled Sheet Piles, Montlake Interchange Area**

### *Portage Bay Bridge Area*

The major vibration generating equipment assumed to be used in the Portage Bay Bridge area are the vibratory pile driver and mounted hammer hoe ram. The vibratory pile driver is assumed to be used to install piles for the temporary work bridge, to remove piles from the existing bridge, and to install piles for the new bridge. The mounted hammer hoe ram is assumed to be used to demolish the existing structure.

The worst-case predicted vibration levels at the properties closest to construction are presented in Table 7-7. The predicted vibration levels for historic properties near construction activities are presented in Table 7-8. Predictions that exceed the appropriate impact threshold are shown in bold and italic font. Predicted vibration contours are shown in Figure 7-9 through Figure 7-11. For pile driving, the worst-case predictions are provided for the west-most pile location and the east-most pile location.

The predicted vibration levels do exceed the damage risk threshold at the closest property during pile driving at the east end of the Portage Bay Bridge. The closest historic property is the NOAA Northwest Fisheries Science Center which has buildings that are eligible for the national register of historic places (damage risk threshold of PPV 0.12 in/sec). In addition, the institution performs vibration sensitive research on site. The predictions presented are for the historic building (east wing) of the Science Center. The predicted vibration levels at the NOAA fishery labs, which are the structures closest to construction, would be 0.270 in/sec .

The predicted vibration levels also exceed the thresholds during demolition at both the closest historic properties and non-historic properties. Figure 7-11 graphically shows the vibration contours at 150 ft where the predicted level is equivalent to the threshold for historic buildings (0.12 in/sec PPV). Potential for vibration impact is predicted at all historic properties within this contour. Mitigation measures should be implemented to ensure that vibration levels do not exceed the damage risk threshold during demolition. In addition, the construction vibration will be strongly perceptible to the nearest residents, which may result in complaints.

**Table 7-7: Predicted Construction Vibration Levels at Closest Properties, Portage Bay Bridge Area**

| Construction Activity | Equipment | Closest Property | Distance to Construction | Predicted PPV at Receiver |
|---|---|---|---|---|
| Portage Bay work bridge pile driving (west end) | Vibratory Pile Driver | 2608 Boyer Avenue East (Queen City Yacht Club) | 110 ft | 0.126 |
| Portage Bay work bridge pile driving (east end) | Vibratory Pile Driver<br>Mounted Hammer Hoe Ram | 2723 Montlake Boulevard NE (NOAA Northwest Fisheries and Science Center) | 250 ft<br>275 ft | 0.051<br>0.062 |
| Existing Portage Bay Bridge demolition | Mounted Hammer Hoe Ram | 2575 West Montlake Place East (residence) | 30 ft | ***0.713*** |

### Table 7-8: Predicted Construction Vibration Levels at Historic Properties, Portage Bay Bridge Area

| Construction Activity | Equipment | Historic Property ID | Distance to Construction | Predicted PPV (in/sec) |
|---|---|---|---|---|
| Portage Bay work bridge pile driving (west end) | Vibratory Pile Driver | 45 | 200 ft | 0.065 |
| | | 48 | 125 ft | 0.110 |
| | | 52 | 240 ft | 0.053 |
| | | 432 | 450 ft | 0.027 |
| | | 433 | 420 ft | 0.029 |
| | | 434 | 380 ft | 0.032 |
| | | 437 | 280 ft | 0.045 |
| Portage Bay work bridge pile driving (east end) | Vibratory Pile Driver | 55 | 550 ft | 0.021 |
| | | 56 | 50 ft | ***0.300*** |
| | | 58 | 660 ft | 0.018 |
| Existing Portage Bay Bridge demolition | Mounted Hammer Hoe Ram | 45 | 130 ft | ***0.142*** |
| | | 48 | 120 ft | ***0.155*** |
| | | 52 | 225 ft | 0.078 |
| | | 55 | 570 ft | 0.028 |
| | | 56 | 60 ft | ***0.333*** |
| | | 58 | 390 ft | 0.042 |
| | | 61 | 540 ft | 0.030 |
| | | 123 | 480 ft | 0.034 |
| | | 125 | 540 ft | 0.030 |
| | | 126 | 455 ft | 0.036 |
| | | 432 | 485 ft | 0.033 |
| | | 433 | 445 ft | 0.037 |
| | | 434 | 400 ft | 0.041 |
| | | 437 | 280 ft | 0.061 |

[1] The locations of the historic properties corresponding to their ID number are shown in Table 3-1.


**Figure 7-9: Predicted Vibration Contours for Portage Bay Bridge Pile Driving, West End**

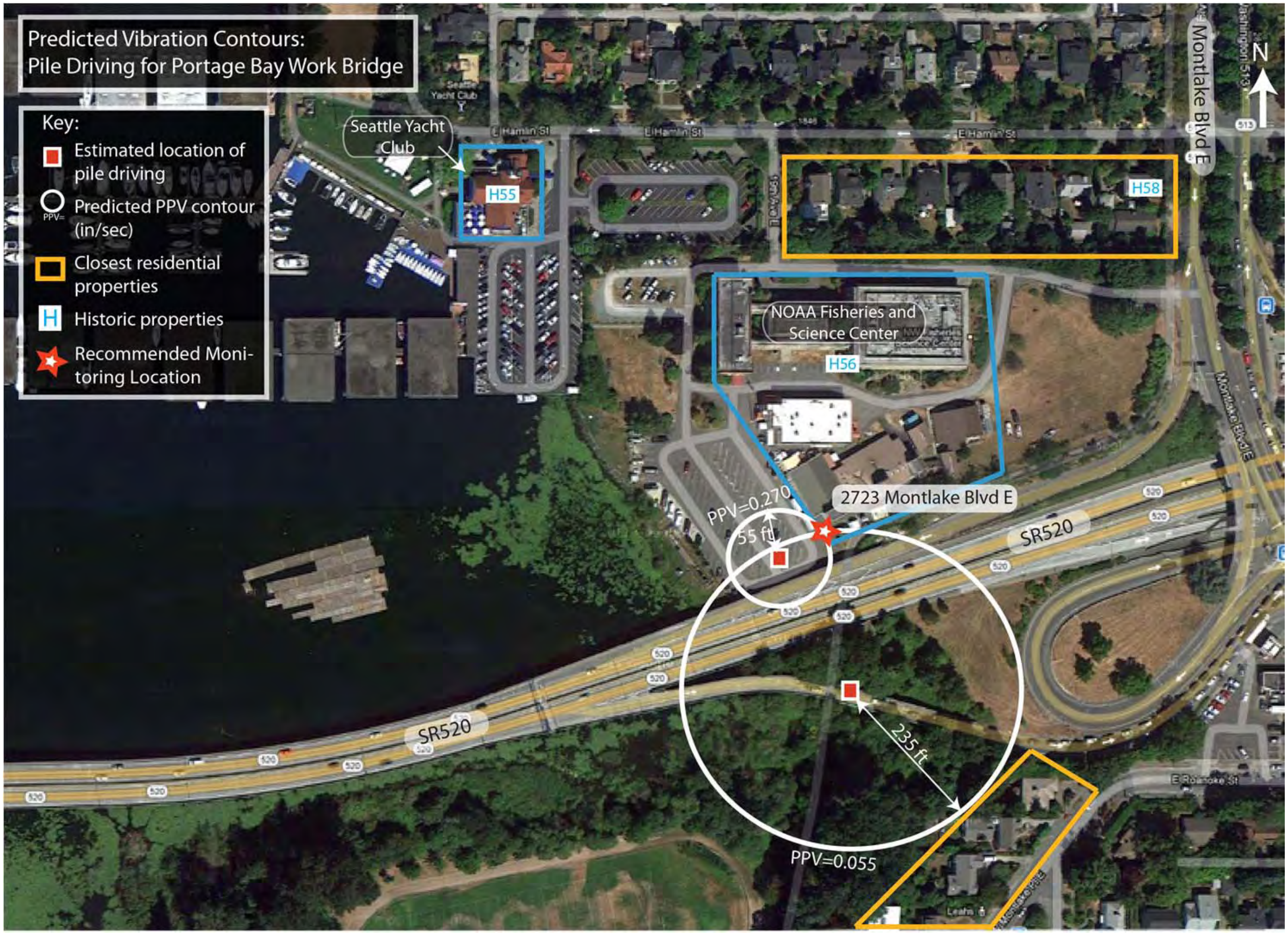


**Figure 7-10: Predicted Vibration Contours for Portage Bay Bridge Pile Driving, East End**

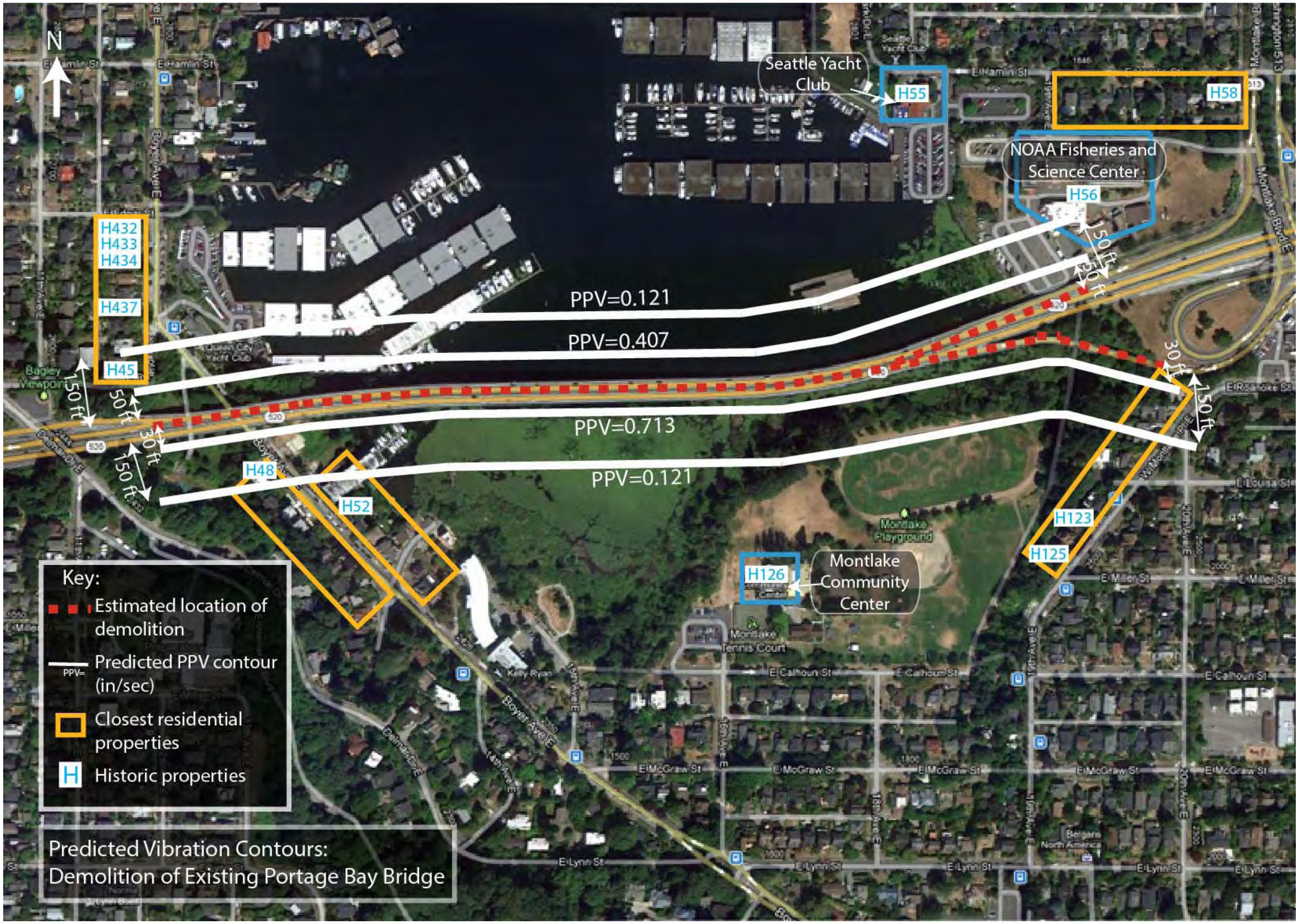


**Figure 7-11: Predicted Vibration Contours for Existing Portage Bay Bridge Demolition**

## 7.3 I-5 Interchange Area

The major vibration generating equipment assumed to be used in the I-5 interchange area is the mounted hammer hoe ram and the auger drill rig. The mounted hammer hoe ram is assumed to be used for limited demolition of the existing Roanoke Street Bridge and for demolition of the existing SR 520 mainline and ramps. The auger drill rig is assumed to be used to drill sheet piles for the construction of the lid.

The worst-case predicted vibration levels at the properties closest to construction are presented in Table 7-9. The predicted vibration levels for historic properties near construction activities are presented in Table 7-10. All predictions that exceed the appropriate damage risk threshold are shown in bold and italic font. Predicted vibration contours are shown in Figure 7-12 through Figure 7-14.

The predicted vibration levels do not exceed the damage risk threshold for the limited demolition of the existing Roanoke Street Bridge at the closest historic or non-historic properties. Therefore, vibration mitigation measures do not need to be implemented during the limited demolition. However, the construction vibration at this level will be strongly perceptible in the nearest buildings, which may result in complaints.

The predicted vibration levels do exceed the damage risk thresholds during demolition of the mainline SR 520 and ramps at both the closest historic properties and non-historic properties. Figure 7-13 graphically shows the vibration contours at 150 ft where the predicted level is equivalent to the threshold for historic building (0.12 in/sec PPV). Potential for vibration impact is predicted at all historic properties within this contour. Mitigation measures should be implemented to ensure that vibration levels do not exceed the damage risk threshold during demolition. In addition, construction vibration at this level will be strongly perceptible to the nearest residents, which may result in complaints.

The predicted vibration levels do not exceed the damage risk threshold at any properties during drilling for sheet piles. Vibration mitigation measures do not need to be implemented during drilling. The construction vibration at this level is likely to be barely perceptible to the nearest residents.

**Table 7-9: Predicted Vibration Levels at Properties Closest to Construction, I-5 Interchange Area**

| Construction Activity | Equipment | Closest Property | Distance to Construction | Predicted PPV at Receiver |
|---|---|---|---|---|
| Limited demolition of existing Roanoke Street Bridge | Mounted Hammer Hoe Ram | 2500 Franklin Avenue East (School) | 80 ft | 0.243 |
| Demolition of existing SR520 mainline and ramps | Mounted Hammer Hoe Ram | 811 E Roanoke Street (Washington State Patrol Building) | 30 ft | ***0.713*** |
| Drilling sheet piles for construction of new overcrossings and integrated lid | Auger Drill Rig | 2422 Federal Avenue East | 60 ft | 0.020 |

**Table 7-10: Predicted Vibration Levels at Historic Properties, I-5 Interchange Area**

| Construction Activity | Equipment | Historic Property ID | Distance to Construction | Predicted PPV (in/sec) |
|---|---|---|---|---|
| Limited demolition of existing Roanoke Street Bridge | Mounted Hammer Hoe Ram | 36 | 280 ft | 0.061 |
| Demolition of existing SR520 mainline and Ramps | Mounted Hammer Hoe Ram | 20 | 275 ft | 0.062 |
| | | 22 | 140 ft | ***0.131*** |
| | | 23 | 120 ft | ***0.155*** |
| | | 25 | 200 ft | 0.089 |
| | | 26 | 240 ft | 0.072 |
| | | 27 | 360 ft | 0.046 |
| | | 36 | 60 ft | ***0.333*** |
| | | 39 | 150 ft | ***0.121*** |
| | | 45 | 120 ft | ***0.155*** |
| | | 48 | 125 ft | ***0.148*** |
| Drilling sheet piles for construction of new overcrossings and integrated lid | Auger Drill Rig | *20* | 330 ft | 0.003 |
| | | *22* | 220 ft | 0.005 |
| | | *23* | 200 ft | 0.005 |
| | | 25 | 220 ft | 0.005 |
| | | 26 | 210 ft | 0.005 |
| | | *27* | 315 ft | 0.003 |
| | | 36 | 90 ft | 0.012 |
| | | 39 | 60 ft | 0.020 |
| | | 45 | 150 ft | 0.007 |
| | | 432 | 450 ft | 0.002 |
| | | 433 | 420 ft | 0.002 |
| | | 434 | 380 ft | 0.003 |
| | | 437 | 280 ft | 0.004 |

[1] The locations of the historic properties corresponding to their ID number are shown in Table 3-1.

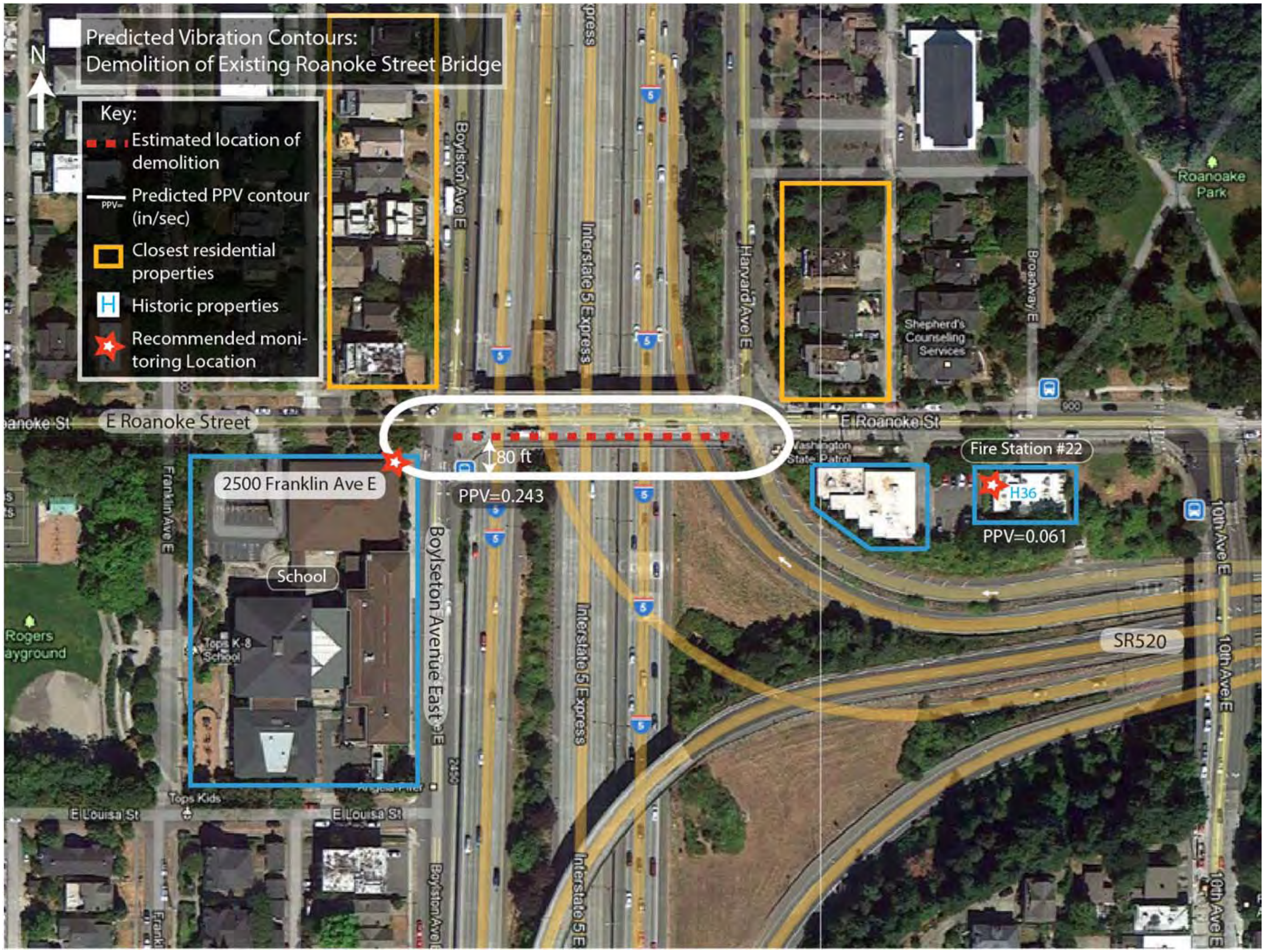


**Figure 7-12: Predicted Vibration Contours for Limited Demolition of Existing Roanoke Street Bridge, I-5 Interchange Area**

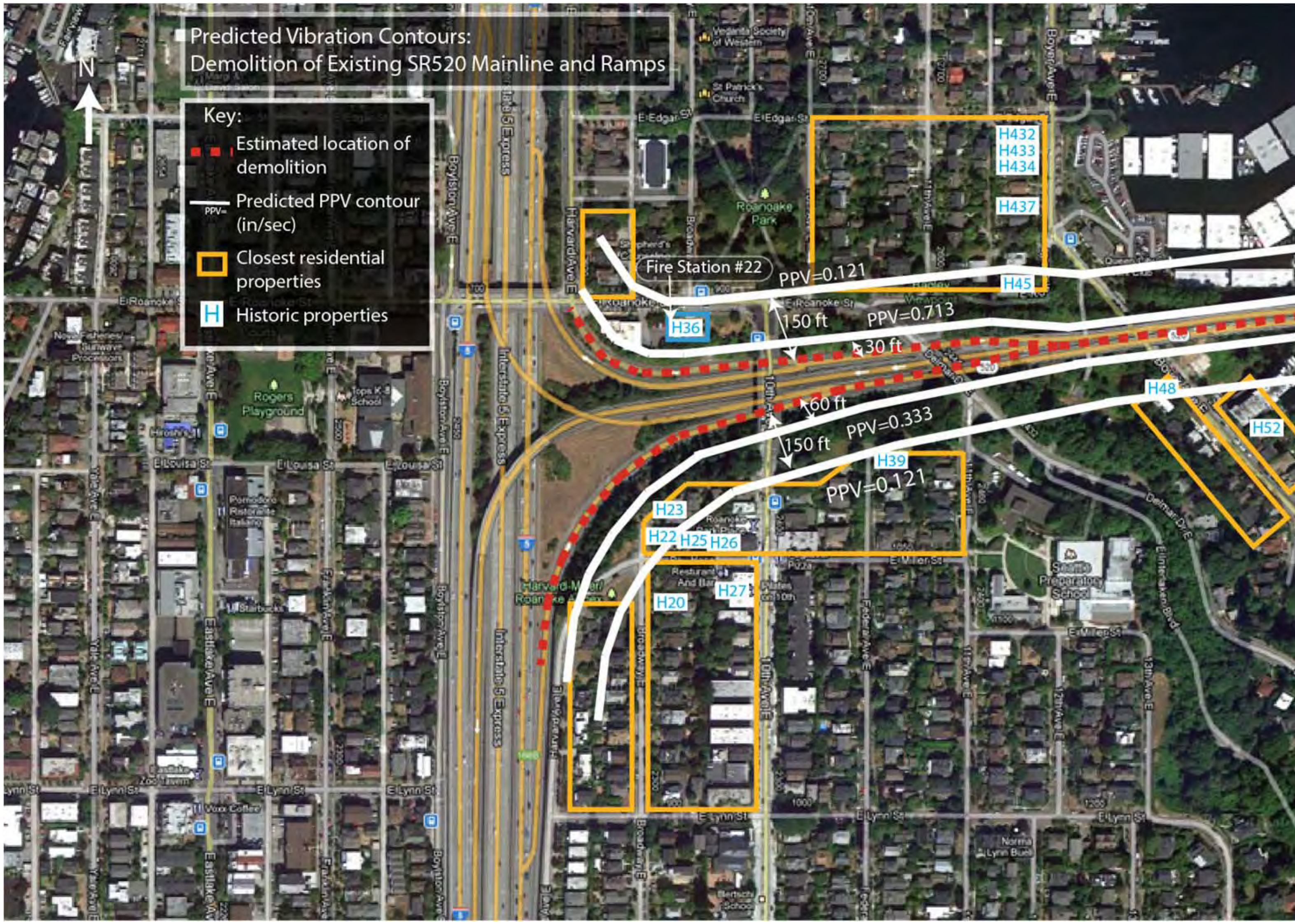


**Figure 7-13: Predicted Vibration Contours for Demolition of Existing SR520 Mainline and Ramps, I-5 Interchange Area**

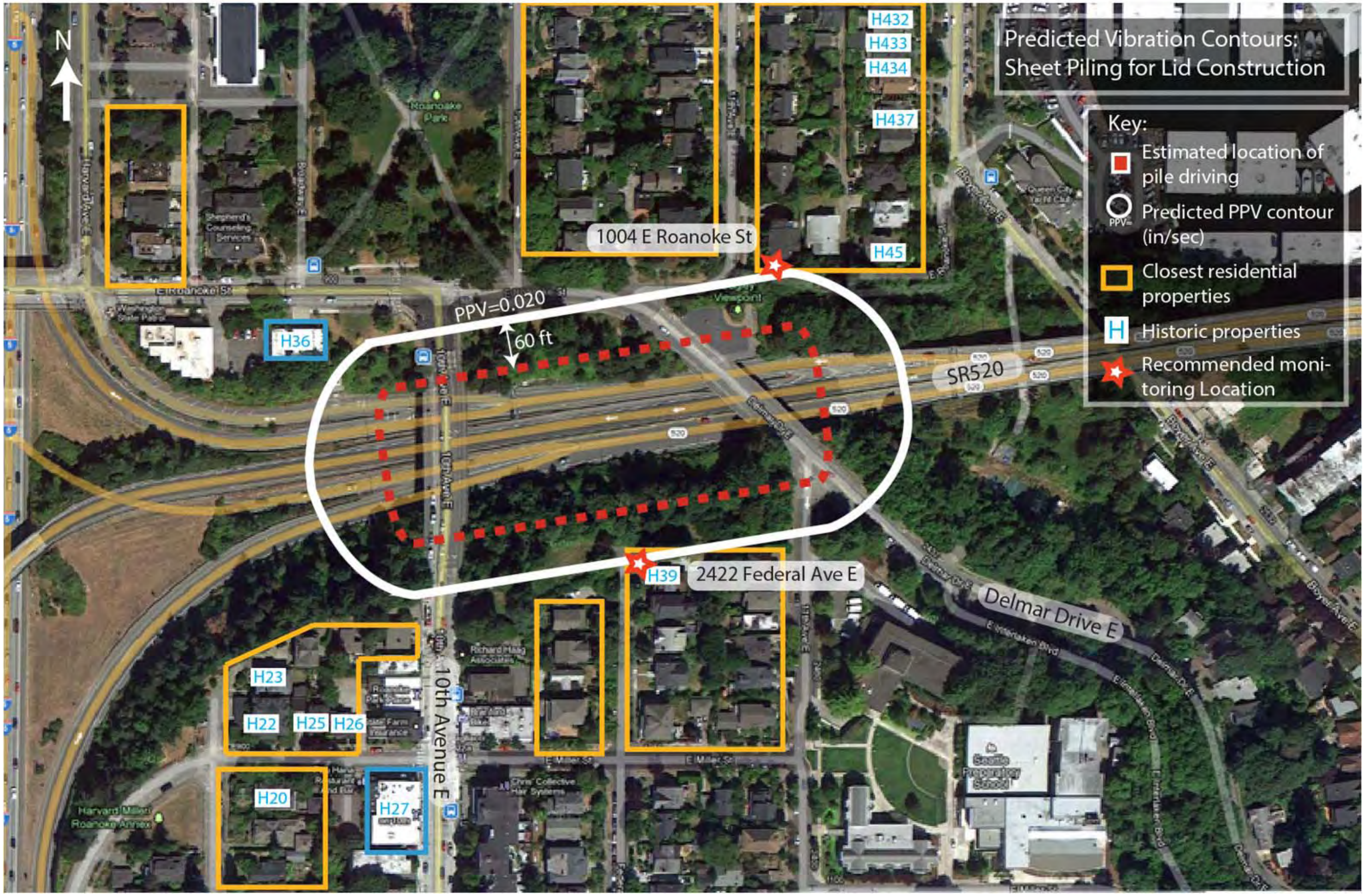


**Figure 7-14: Predicted Vibration Contours for Drilling Sheet Piles for Lid Construction, I-5 Interchange Area**

## 7.4 SR 520 Haul Routes

Materials would be transported to and from the SR 520 construction work areas by trucks and barges. Barges would provide access to offshore work areas. Trucks would travel over identified haul routes through Seattle to SR 520, I-5, and I-405. During the environmental planning process, construction staging plans and haul routes has been developed to improve traffic management, to respond to public concerns and comments, and to accommodate changes in construction schedule.  Selection of haul routes is intended to keep the majority of haul route traffic on major freeways such as I-5, SR 520, and I-405. However, there will be times when city streets will need to be used as secondary haul routes. Secondary haul routes for the SR 520, I5 to Medina project will be selected based on criteria such as shortest off-highway mileage, providing access to locations needed for construction where direct highway access is unavailable, and the ability to accommodate truck traffic. Final haul routes will be identified during the street use permitting process for each individual jurisdiction. This permit process typically takes place during the final design phase and prior to construction. Construction haul routes can temporarily increase truck traffic volumes, with accompanying potential for increases in existing traffic noise.

The potential for ground vibration generated by haul trucks are based on the condition of the roadway. Ground vibration generated by rubber tired vehicles are not usually of concern unless the roadway conditions have rough or irregular surfaces, ruts or potholes. These discontinuities in the roadway will cause heavy vehicles such as haul trucks to generate higher levels of ground vibration than smoother well maintain roads.

The results of a study conducted by the California Department of Transportation (Caltrans) of highway trucks where residents complained that a vertical discontinuity from potholes in the nearby freeway's travel lanes caused heavy trucks to bounce resulting in readily perceptible damage-inducing groundborne vibration is presented in Figure 7-15. Measurements of the truck vibration levels were conducted using guidance from Caltrans' Transportation and Construction-Induced Vibration Guidance Manual (June 2004). The results of these measurements indicate that buildings within 20 feet of the trucks would generate ground vibration that exceed the criteria for buildings extremely susceptible to vibration damage such as historic properties. This is a worst case scenario that would result when the haul routes are along roads that are poor condition with ruts and potholes. To minimize and avoid these levels of ground vibration from haul trucks, the Contractor, in coordination with the City of Seattle, should be responsible for repairing any ruts or potholes that may occur along the haul routes.

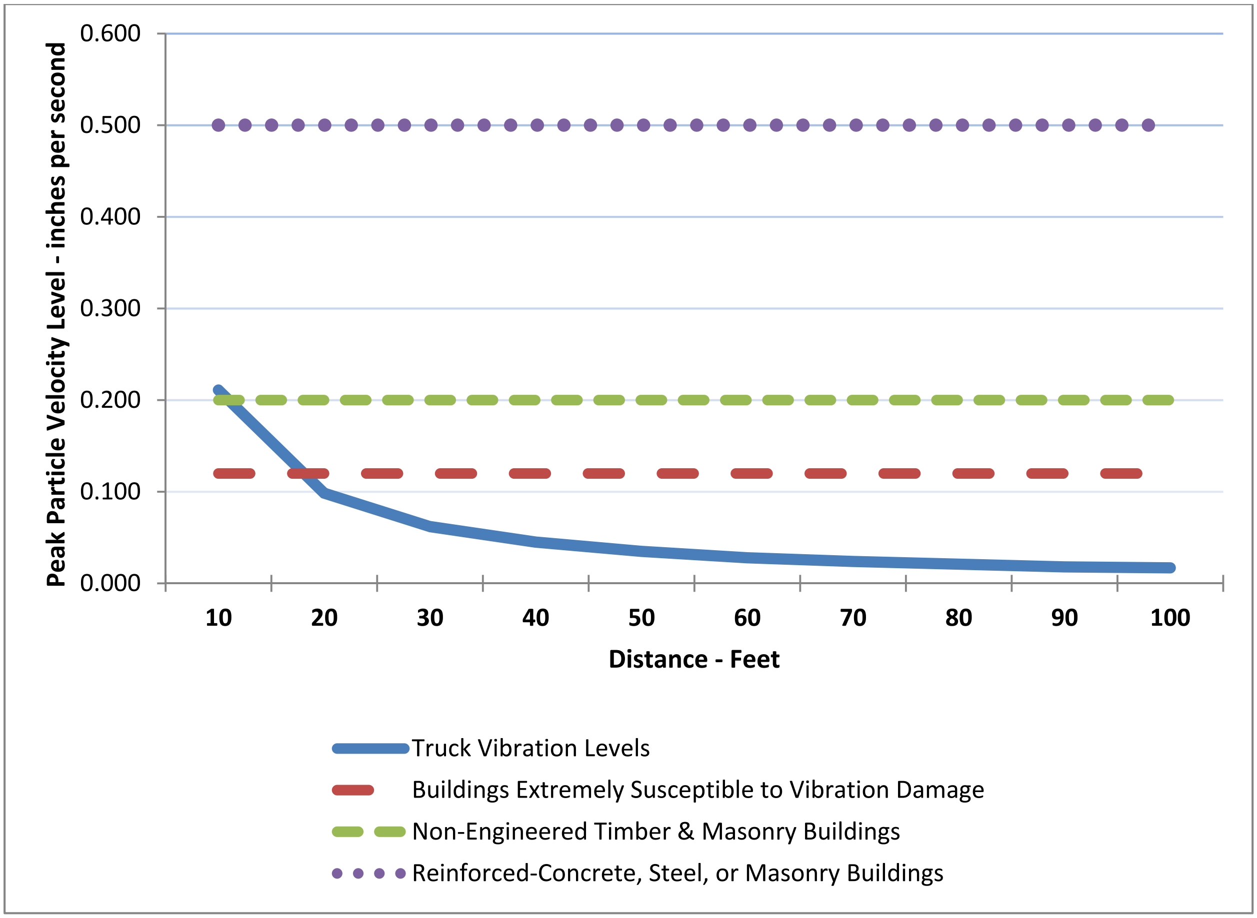


**Figure 7-15: Expected Haul Truck Vibration Levels**

## 7.5 Protection of Steep Slopes during Construction

The potential effects of construction vibration on steep slopes is dependent on the geology and soil conditions of these areas which should be evaluated by a geotechnical engineer. Where there are slopes of concern near construction sites, the Contractor should establish a displacement reference point (DRP) before construction begins. During construction the DRP can be monitored to determine if there is any movement or displacement of the slope that would need to be mitigated.

# 8 *Mitigation Measures*

This section presents recommended mitigation measures for the major noise and vibration generating construction activities modeled in this Plan, as well as general control measures that should be implemented by the Contractor in all construction areas. In addition, the Contractor should perform vibration monitoring at the closest receivers. Recommendations for vibration monitoring during the Project are presented in Section 9.

## 8.1 West Approach Area

No noise or vibration impact was identified in the West Approach area. 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 vibration monitoring at the closest receivers.

## 8.2 Montlake Interchange Area

Noise impact was predicted at the closest properties during demolition and lid construction. The recommended mitigation measures are as follows:

- Demolition: Use temporary moveable noise barriers around equipment to shield the sensitive receivers from loud equipment, when feasible.
- Lid construction: Use temporary moveable noise barriers to shield the sensitive receivers from loud equipment, when feasible. The barriers should be placed close to the equipment and or the construction activity to block the line-of-sight between equipment and receivers.

Vibration impacts were predicted at the closest properties during demolition. The recommended mitigation measures are to use alternative, non-impact demolition methods when in close proximity to building structures.

In addition, the Contractor should implement the general noise and vibration control measures at all sites as well as perform vibration monitoring at the closest receivers.

## 8.3 Portage Bay Bridge Area

Noise impact was predicted at the closest properties during pile driving and demolition. The recommended mitigation measures are as follows:

- Pile Driving: When possible, use a shroud around the anvil of the impact hammer to shield the sensitive receivers from noise from the pile driving.
- Demolition: Use temporary moveable noise barriers to shield the sensitive receivers from loud equipment.

Vibration impact was predicted at the closest properties during pile driving and demolition. The recommended mitigation measures are as follows:

- Pile Driving: Use of vibratory pile drivers that generate lower vibration levels than impact pile driving.
- Demolition: When possible use alternative, non-impact demolition methods when near sensitive receivers.

In addition, the Contractor should implement the general noise and vibration control measures at all sites as well as perform vibration monitoring at the closest receivers.

## 8.4 I-5 Interchange Area

Noise impact was predicted at the closest receivers during demolition and lid construction. The recommended mitigation measures are as follows:

- Demolition: Use temporary moveable noise barriers to shield the sensitive receivers from loud equipment.
- Lid Construction: Use temporary moveable noise barriers to shield the sensitive receivers from loud equipment.

Vibration impact was predicted at the closest properties during demolition. The recommended mitigation measures are to use alternative, non-impact demolition methods when in close proximity to building structures.

## 8.5 General Noise and Vibration Control Measures

When daytime 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. However, for certain types of construction such as installing piles, the Contractor will need a Noise Variance from the City so there is no disruption or delay in these activities.

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 feasible.
- Impact or impulse tools should not be used from 7 p.m. to 10 a.m.
- Use electric welders powered from utility main lines instead of electric generators/welders.
- Limit the use of public address systems during nighttime hours, except for emergency notifications.
- Grade surface irregularities on construction sites to prevent impact noise and ground vibrations generated by passing vehicles.
- Use concrete decking for cut-and-cover construction sites.

Where the vibration threshold limits identified in Section 0 are exceeded at the monitoring locations the Contractor shall stop all work and either modify the activity causing the exceedance or modify the means and methods of construction to reduce the vibration levels.

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
- Avoid pavement breakers and vibratory rollers and packers near sensitive buildings

# 9 *Vibration Monitoring*

Vibration monitoring will be performed at locations in the vicinity of all of the construction areas. The vibration monitoring should be continuous and will require the installation of semi-permanent monitoring stations. The monitors should be capable of measuring data unattended and sending data by wireless modem to several different parties including the WSDOT Project Engineer or designee to ensure that the levels do not exceed the thresholds defined in this report.

The recommended vibration monitoring locations to be used by the Contractor in each of the different construction areas are shown on **Error! Reference source not found.** through Figure 7-14. The following sections list the addresses of the vibration monitoring sites for each construction area. In general, the vibration monitoring locations are at the nearest property and, when the nearest property is not historic, a second vibration monitoring location is recommended at the nearest historic property.

## 9.1 West Approach Area

Vibration monitoring in the West Approach area should be performed at the following locations during the specified activity:

- Pile driving, west end: 2465 Lake Washington Boulevard East (historic property ID 184)
- Pile driving, east end: 2411 42nd Avenue East (historic property ID 226)
- Demolition of existing west approach: 2411 42nd Avenue East (historic property ID 226)
- Demolition of Lake Washington Ramps: 2511 Lake Washington Boulevard East (non-historic residence) and 2451 26th Avenue East (historic property ID 199)

## 9.2 Montlake Interchange Area

Vibration monitoring in the west approach area should be performed at the following locations during the specified activity:

- Pile Driving at Bascule Bridge: 2112 E Shelby Street (no-historic residence) and 2111 East Shelby Street (historic property ID 90)
- Demolition of existing interchange: Locate monitors at residences nearest to ongoing demolition. Due to the large area of demolition and proximity of residences, the monitors will have to move as construction progresses. During any given activity, a vibration monitor should be at the nearest structure and at the nearest historic property.
- Lid Construction: 2151 E Hamlin Street (non-historic residence) and 2231 Lake Washington Boulevard East (historic property ID 169)

## 9.3 Portage Bay Bridge Area

Vibration monitoring in the Portage Bay Bridge area should be performed at the following locations during the specified activity:

- Pile Driving (west end only): 2608 Boyer Avenue East (non-historic, Queen City Yacht Club), and 2545 Boyer Avenue East (historic property ID 48)

- Pile Driving (east end only): 2723 Montlake Boulevard East (historic property ID 56, NOAA Northwest Fisheries Science Center)
- Demolition of existing bridge: Locate monitors at residences nearest to ongoing demolition. Due to the large area of demolition and proximity of residences, the monitors will have to move as construction progresses. During any given activity, a vibration monitor should be at the nearest structure and at the nearest historic property.

## 9.4 I-5 Interchange Area

Vibration monitoring in the I-5 Interchange area should be performed at the following locations during the specified activity:

- Limited Demolition at Roanoke Street Bridge: 2500 Franklin Avenue East (school) and 901 East Roanoke Street (historic property ID 36)
- Demolition of SR520 mainline and ramps: Locate monitors at residences nearest to ongoing demolition. Due to the large area of demolition and proximity of residences, the monitors will have to move as construction progresses. At any given time, a vibration monitor should be at the nearest structure and at the nearest historic property.
- Lid Construction: 1004 E Roanoke Street (non-historic residence) and 2422 Federal Avenue East (historic property ID 39)

## 9.5 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.

<u>Location of Vibration Monitors:</u> 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.

<u>Data Acquisition:</u> 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.

# References

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

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

Greene, M, ICF International, Inc, Shake, Rattle & Roll? Result of a Vibration Measurement Study Near a Heavily Traveled Freeway, Transportation Research Board (TRB) Winter 2009.

# 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 9-1 includes examples of A-weighted sound levels from common indoor and outdoor sounds.

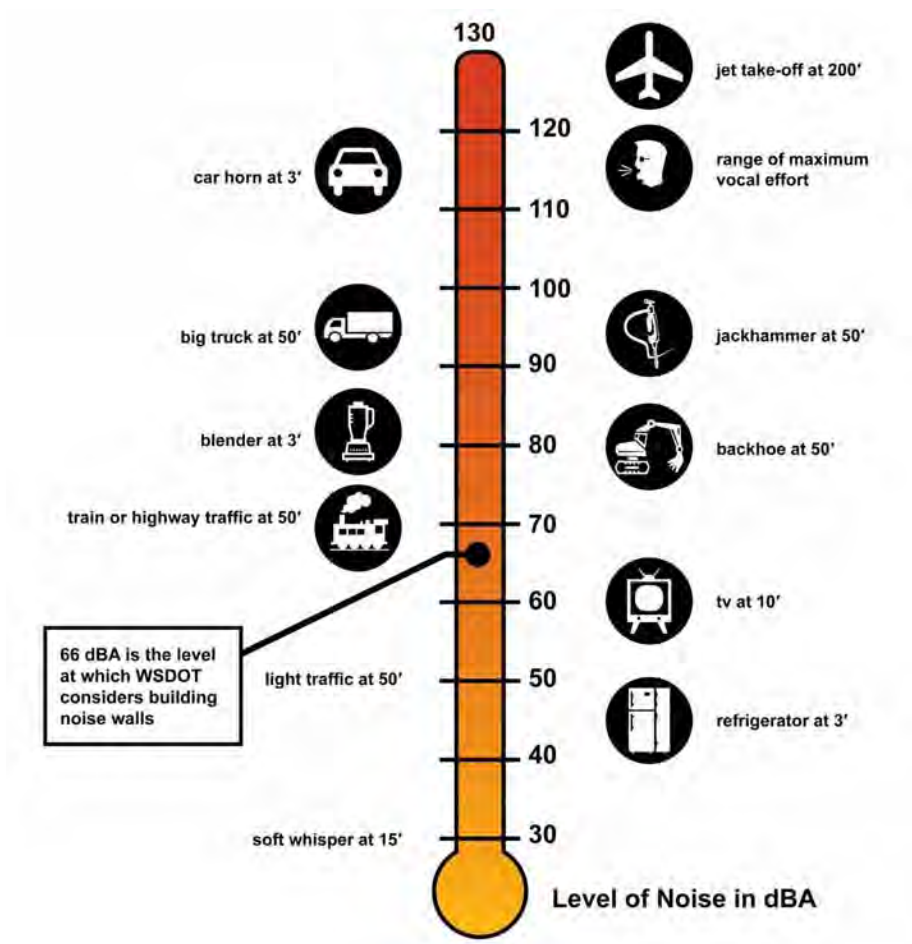


**Figure 9-1: Typical Outdoor and Indoor Noise Levels**

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): T**he 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.

## 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 rail transit 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 9-2 shows typical RMS vibration velocity levels from rail and non-rail sources as well as the human and structure response to such levels.

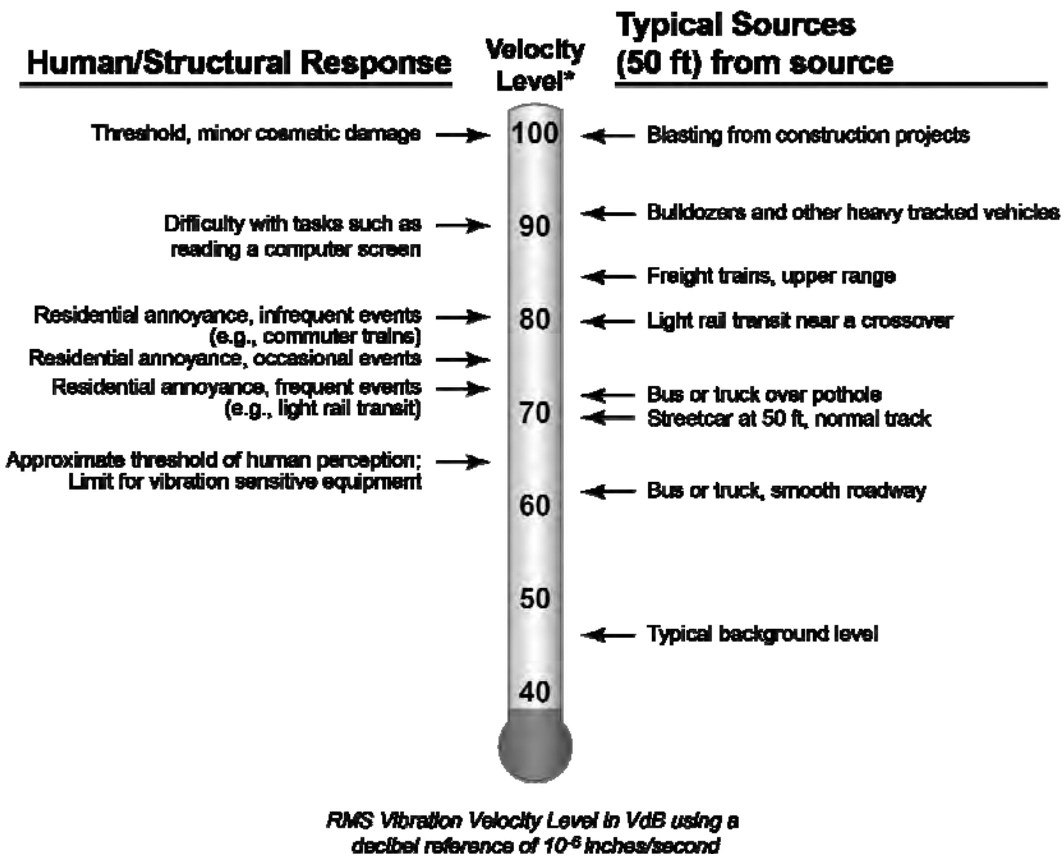


**Figure 9-2: Typical RMS Vibration Velocity Levels**

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.