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MEMORANDUM

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Date: August 10, 2018

Subject: **DRAFT:** Construction Noise and Vibration Assessment for the Washington Boulevard Stormwater and Urban Runoff Project

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1. EXECUTIVE SUMMARY

Construction of the Washington Boulevard Stormwater and Urban Runoff Project has the potential to create noise and vibration impacts to the surrounding community. Noise and vibration predictions were made to determine the location and amount of the potential impacts. For construction operations where an exceedance of the local regulation is expected, mitigation measures are recommended. Table 1 provides a summary of the recommended mitigation measures for each construction operation.

Table 1: Recommended Mitigation Measures by Operation

Operation	Noise Wall	Additional Noise Mitigation	Remaining Impacts After Mitigation Implementation
Op1	8 ft	-	0
Op2	8 ft	Pavement Grinding[2]	0
Op3	8 ft	-	0
Op4	8 ft	Drilled Piles[3]	1 exceedance < 1 dBA
Op5	8 ft	Drilled Piles[3]	0
Op6[1]	8 ft	Drilled Piles[3]	0
Op7[1]	8 ft	-	3 exceedances at business structures (not nighttime sensitive)
Op8	8 ft	-	1 exceedance < 1 dBA
Op9	12 ft	-	1 exceedance < 1 dBA
Op10	8 ft	-	1 exceedance < 1 dBA
Op11	8 ft	-	1 exceedance < 1 dBA
Op12	8 ft	-	0
Op13	8 ft	-	0
Op14	8 ft	Pavement Grinding[2]	2 exceedances of ~1 dBA

[1] Operations 6 and 7 take place at night.
[2] Pavement grinding is a quieter alternative to sandblasting when removing traffic striping.
[3] Drilled piles eliminate all noise & vibration impacts, and sonic pile driving eliminates vibration impacts but not noise impacts.

2. INTRODUCTION

This technical report presents a noise and vibration analysis which was conducted to determine the community impact during construction of the proposed the Washington Boulevard Stormwater and Urban Runoff Project. All construction takes place along Washington Boulevard between Alla Road and Carter Avenue, with a majority of the work taking place in the City of Culver City and a small amount of work to take place in the City of Los Angeles. Figure 1 shows an overview of the project area, including clusters of nearby sensitive noise and vibration receivers which have been grouped by land use and labeled. Receivers located in Culver City are labeled as S1 – S4, B1 – B18, M1 – M4, and C1 – C2. All other groupings are located entirely in Los Angeles.

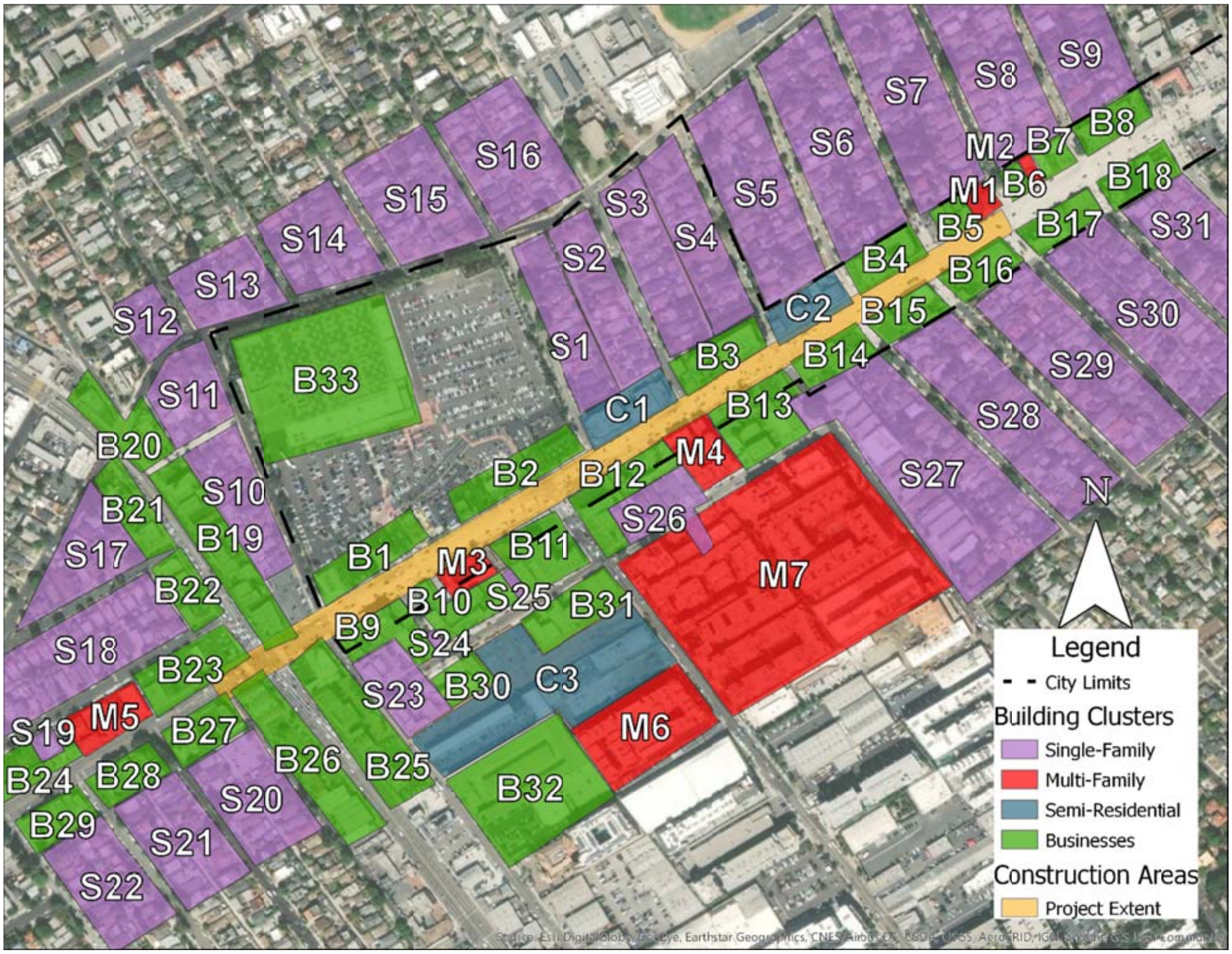

Figure 1: Overview of Sensitive Receiver Groupings in the Project Area.

The project is designed to capture and remove pollutants from stormwater and urban runoff before returning it to the water supply system. Construction activities include the installation of pumps, pipes, and a subsurface storage tank designed to hold approximately 132,000 cubic feet of water. In addition, the driveway entrances to the Costco (receiver B33) parking lot will be replaced and medians will be added to the street along Washington Boulevard. Equipment used during these construction activities produce noise and vibration which have the potential to negatively impact the surrounding community. This report presents the results of an assessment which predicts the noise and vibration levels at nearby homes and businesses during the various construction stages. These estimated noise and vibration levels are then compared against limits set by the City of Culver City Municipal Code (CCMC), the City of Los Angeles Municipal Code (LAMC), and the Caltrans Construction Vibration Guidance Manual[*] In cases where the predicted levels exceed the limits set by the code, mitigation measures are recommended.

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[*] Transportation and Construction Vibration Guidance Manual. Caltrans, Division of Environmental Analysis (2013)

3. CONSTRUCTION ACTIVITIES

The work for this project occurs in multiple locations along Washington Boulevard on the western edge of the City of Culver City, with a small portion of the work to occur within the City of Los Angeles. Project work areas were identified using the 75% submittal design drawings, which includes 3 phases of work. Each phase of work is broken down into stages, where each stage includes work completed in the same area. Figure 2 is an overview of the project area showing where the work for each stage of the construction will take place.

Current work schedules for the construction include roughly 50 subtasks, each requiring a different set of construction equipment with work occurring in different locations. To simplify the analysis for the project, subtasks that will occur in the same area at a similar time were grouped into one of 14 operations. For some operations (specifically operations 1, 2, 12, 13, and 14) tasks are planned for multiple locations along the project area. In those cases, multiple noise models were created to estimate the noise levels at each receiver when the equipment operates in each different location along the project area. For each operation, the highest estimated noise level at each receiver was used to determine possible impacts.

3.1 Construction Operation Breakdown

A breakdown of the work included in each operation and where the operation is assumed to take place is presented below:

Operation 1: Mobilization, erosion and sediment control, and construction signs and notices. Modeling assumed mobilization will occur primarily in the Phase 1A work area, with erosion control and construction signs being implemented concurrently along the entire project work area.

Operation 2: Removal of existing striping and installation of temporary striping and traffic control barriers. Modeling assumed traffic control work will occur along the entire project work area.

Operation 3: Removal and disposal of concrete paving and base material prior to storage tank installation. Modeling assumed this work will occur in the Phase 1A work area.

Operation 4: Installation of concrete subsurface storage tank and associated access shafts. Modeling assumed this work will occur in the Phase 1A work area.

Operation 5: Trenchless installation of line “D” and line “E” diversion pipes (between diversion and subsurface tank). Modeling assumed the boring machine and other equipment will be operating in the Phase 1B work area.

Figure 2: Locations of Nighttime Noise Measurement and Construction Stages.

<u>Operation 6</u>: Nighttime work in the City of Los Angeles, including excavation, sheet pile driving, and trenchless installation of the line “F” sewer connection pipe. Modeling assumed the boring machine and other equipment will be operating in the Phase 1B work area.

<u>Operation 7</u>: Nighttime work in the City of Los Angeles, including sewer connections, swing check valve installation, and thrust block installation. Modeling assumed the work will occur in the Phase 1C work area.

<u>Operation 8</u>: Storm drain construction including sumps, gutters, and open trench piping. Modeling assumed the work will occur in the southern section (eastbound side of Washington Blvd) of the Phase 2A work area.

<u>Operation 9</u>: Construction of the diversion structure, including removal and replacement of the sidewalk. Modeling assumed the work will occur in the northern section (westbound side of Washington Blvd) of the Phase 2A work area.

<u>Operation 10</u>: Installation of the pretreatment unit, high and low flow pump stations and associated piping for the diversion. Modeling assumed work will occur in the Phase 1B work area.

Operation 11: Installation and connection of electrical housing structures for the diversion including the electrical cabinet, conduits, wiring, and pull boxes. Modeling assumed work will occur in the Phase 2B work area.

Operation 12: Construction of concrete paving and base material. Modeling assumed work in the Phase 1A, 1B, & 1C work areas, as well as the Costco entrance driveways (with work to occur at separate times).

Operation 13: Construction of new medians along Washington Blvd. Modeling assumed work will occur in the five Phase 3A work areas, two of which are located within the Phase 1A work area.

Operation 14: Removal of temporary traffic striping and barriers, installation of final striping, irrigation, planting, and punchlist. Modeling assumed this work will occur along the entire project work area.

4. PRE-CONSTRUCTION NIGHTTIME NOISE MEASUREMENT

Existing noise conditions were documented at sensitive receivers closest to the construction areas to determine the baseline ambient noise levels before nighttime construction activities begin. The location of the noise measurement (red pin) is shown in Figure 2. A sound level meter was placed in front of a single-family residence at 1147 Harrison Avenue, which is adjacent to where nighttime construction activity will occur. The sound level meter recorded ambient noise levels from 3:00 PM on July 5, 2018 until 12:15 PM on July 6, 2018. Figure 3 shows the recorded noise levels at that site during the nighttime hours of 9:00 pm to 7:00 AM. Due the limited extent of the nighttime activities only a single measurement was conducted.

The existing noise measurements are used as the initial basis to establish the noise level limits for a noise variance from the City of Los Angeles for construction during the nighttime hours of 9:00 PM to 7:00 AM. The measured nighttime ambient noise level was determined to be 61 Leq (dBA); see Appendix A: Fundamentals of Noise for the definitions of noise and vibration terms used in this report.

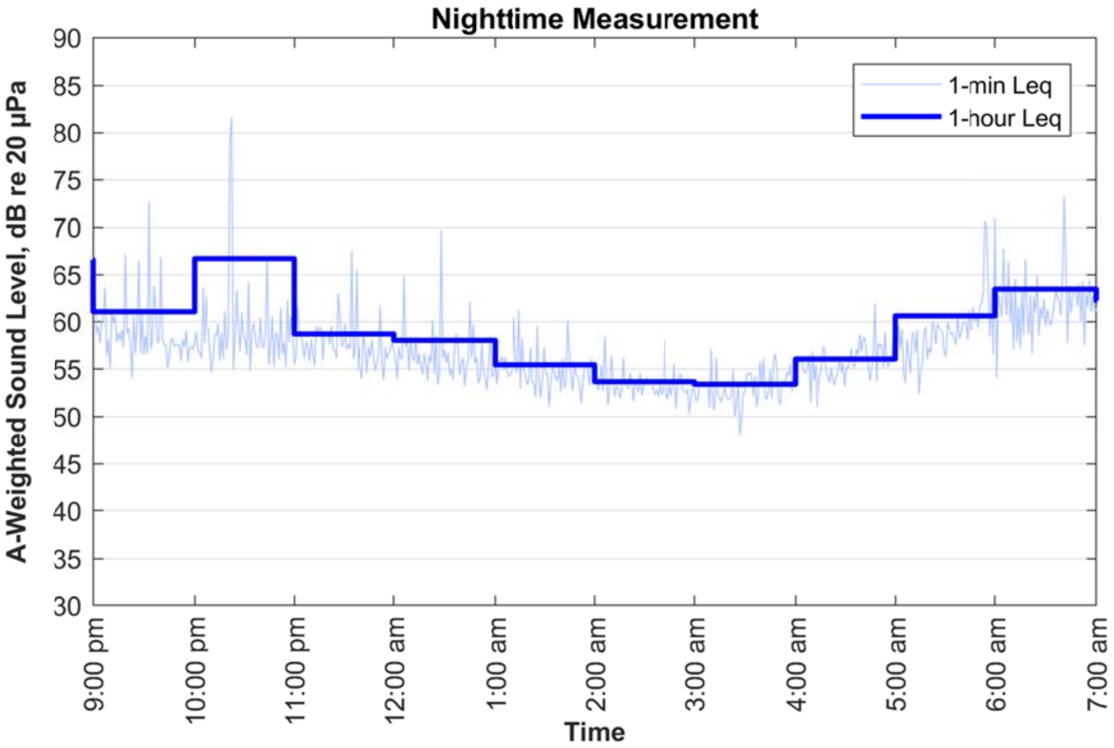

Figure 3: Ambient Noise Measured in the Project Area During Nighttime Hours.

5. CONSTRUCTION NOISE LIMITS

The construction activities for this project are subject to the regulations set forth in both the City of Los Angeles Municipal Code (LAMC) and the City of Culver City Municipal Code (CCMC). These codes of regulation restrict the hours when construction activities may take place and may set limits on noise levels due to construction activities.

5.1 City of Culver City Noise Limits

Section 9.07.035 of the CCMC prohibits construction except between the hours of 8:00 AM and 8:00 PM Monday through Friday, 9:00 AM and 7:00 PM Saturdays, and 10:00 AM and 7:00 PM Sundays. However, construction activities may by authorized outside of these hours if an application for a temporary use permit is approved as per Chapter 17.520 of the CCMC.

Section 9.04.015(H) of the CCMC does not set an explicit limit for noise levels, and instead prohibits the generation of “any loud or unusual noise or sound, disturbing the peace.” Since the CCMC does not specify limits on construction noise levels this analysis defers to those limits specified in the City of Los Angeles Municipal Code.

5.2 City of Los Angeles Noise Limits

Section 112.05 of the LAMC sets a maximum daytime noise level for powered equipment of 75 dBA at a distance of 50 feet when operated within 500 feet of a residential zone. However, compliance with this standard is not required where “technically infeasible”. Technically infeasible means that the established noise limits cannot be met with at the project site despite the use of mufflers, shields, sound barriers, and/or other noise reduction devices or techniques employed during the operation of equipment. This analysis uses a daytime limit of 75 dBA for residential receivers.

The LAMC Section 41.40 also prohibits construction between the hours of 9:00 PM and 7:00 AM Monday through Friday, and between 6:00 PM and 8:00 AM Saturday. No construction is allowed on Sundays or holidays. Construction activities may be authorized outside of these hours if a written application for a variance is approved by the Executive Director of the Board of Police Commissioners. If a noise variance is obtained, construction can be conducted during nighttime hours with a noise limit of 5 dB above the measured ambient.

A pre-construction noise measurement was conducted at the sensitive receivers adjacent to the nighttime construction areas to determine the pre-construction ambient noise levels and nighttime construction noise limits. The noise measurement results are presented in Section 4 of this report and the nighttime ambient was determined to be 61 Leq (dBA), thus the nighttime construction noise limit for receivers is 66 Leq (dBA), see Table 2.

Since most construction operations for this project produce noise exceedances at receivers located within both Los Angeles and Culver City, it is recommended that the contractor adhere to both the CCMC and the LAMC for all phases of construction. Therefore, unless additional permission is granted through a variance (LAMC) and a temporary use permit (CCMC) construction should only take place between the hours of 8:00 am and 8:00 pm Monday through Friday, 9:00 am and 6:00 pm Saturdays, with no construction allowed on Sundays and holidays.

Table 2: Summary of Construction Noise Limits

Construction Activity	Noise Limit[1], dBA
Daytime (7:00 A.M. – 9:00 P.M.)[2]	75 dBA
Nighttime (9:00 P.M. – 7:00 A.M.)	61 dB + 5 dB

[1]Noise limit applies to the facade of the closest noise sensitive property.
[2]Construction should not begin until 8:00 am and cease by 8:00 pm on weekdays unless a temporary use permit is granted by Culver City.

6. CONSTRUCTION VIBRATION LIMITS

The primary concern regarding construction vibrations is the potential for damage to structures. The Caltrans Construction Vibration Guidance Manual includes thresholds for when buildings are at risk for potential damage. The limits in the Caltrans Guidance Manual are listed in terms of peak particle velocity (PPV), which is often used when monitoring blasting and construction vibration because it relates to the stresses that are experienced by the structures. PPV is the maximum instantaneous positive or negative peak of an oscillating vibration signal, which is reported here using velocity in inches/second (in/sec). Construction vibration limits are not based on existing vibration levels.

Stricter limits are set for buildings which are historic or fragile when compared to modern structures. There are no structures on the National Register of Historic Places located near the project area. In addition, the Culver City Historic Preservation Advisory Committee (HPAC) generated a report in 1990 which lists landmarks and significant structures in the city. None of the structures listed in that report are located near the construction area. Most buildings located along Washington Boulevard near the work site were found to be of modern construction and unlikely to require limits for fragile buildings. One building of note is located in receiver group B3 at 13323 W. Washington Boulevard. This building, which was built in 1984 and therefore is of modern construction, has a unique architecture and may warrant a pre-construction crack inspection as described in the vibration control measure Section 9.2 of this report.

The Caltrans Guidance Manual suggests a limit for new residential structures and modern industrial/commercial buildings at 0.5 in/sec PPV for the type of equipment used in this project. It should be noted that the vibration limits are levels at which the onset of potential risk for cosmetic architectural damage may begin, not the level at which structural damage will occur. Examples of architectural damage are cracked plaster, stucco or tile. Examples of structural damage are cracking of floor slabs, foundations, columns, and beams.

Table 3: Construction Vibration Damage Risk Limits

Structure and Condition	Peak Particle Velocity (in/sec)	
	Transient Source	Continuous/Frequent Intermittent Sources
Extremely fragile historic buildings, ruins, ancient monuments	0.12	0.08
Fragile buildings	0.2	0.1
Historic and some old buildings	0.5	0.25
Older residential structures	0.5	0.3
New residential structures	1.0	0.5
Modern industrial/commercial buildings	2.0	0.5
Source: Caltrans Transportation and Construction Vibration Guidance Manual (2013), Table 19		

7. CONSTRUCTION NOISE PREDICTIONS

7.1 Noise Predictions Methodology

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

- An emission model to determine the noise generated by the equipment at a reference distance.
- A propagation model that calculates how the noise level varies with distance.
- A prediction model that sums the noise of each source at sensitive locations.

The noise modeling includes the effects of ground cover, the shielding of building structures, and the reduction provided by a noise barrier wall (if one is specified in the construction plans). The source noise levels used in the model for different pieces of construction equipment are based on the actual measured noise level data presented in Table 4.

Table 4: Construction Equipment Noise Emission Levels

Equipment Description	Lmax Noise Limit at 50 ft., dB Slow	Is Equipment an Impact Device?
All other equipment > 5HP	85	No
Backhoe	78	No
Compactor (ground)	83	No
Compressor (air)	78	No
Concrete Mixer Truck	79	No
Concrete Saw	90	No
Crane	81	No
Dozer	82	No
Dump Truck	76	No
Excavator	81	No
Flat Bed truck	74	No
Front End Loader	79	No
Generator	81	No
Horizontal Boring Machine	82	No
Impact/Vibratory Pile Driver	101	Yes
Jackhammer	89	Yes
Mounted Impact Hammer	90	Yes
Pavement Scarafier	85	No
Pumps	81	No
Roller	80	No
Sand Blasting (single nozzle)	96	No
Slurry Trenching Machine	80	No
Vacuum Street Sweeper	82	No
Welder / Torch	74	No
Source: Federal Highway Administration (FHWA) Roadway Construction Noise Model, 2006		

7.2 Construction Noise Predictions

Noise prediction models were developed for each construction operation based on the project plan drawings and the current means and methods planned for the construction phases. Table 5 compares the predicted noise levels to the established limits for each sensitive receiver likely to be affected by the construction activities. For cells where a number is listed a noise limit exceedance is expected, and the value indicates how far over the limit (75 dBA daytime and 66 dBA nighttime) the noise levels are expected to be. If no value is listed, the predicted noise levels do not exceed the limits. The predictions are conservative estimates, meaning that actual levels are unlikely to exceed the predicted levels in most cases under normal conditions.

As shown in Table 5, the construction noise levels at several receivers would exceed the noise limit by up to 25 dB depending on the receiver location and construction activity. The construction activity producing the largest noise exceedance is the impact pile driving. Recommendations for reducing these exceedances is described subsequently.

Table 5: Construction Noise Exceedance – Leq (dBA), Unmitigated

Receiver ID	Construction Operation Phases													
	Op1	**Op2**	**Op3**	**Op4**	**Op5**	**Op6***	**Op7***	**Op8**	**Op9**	**Op10**	**Op11**	**Op12**	**Op13**	**Op14**
S1		1.3		11.3										0.4
S2			1.6	12.3										1.1
S6														4.9
S10						13.4					6.8			
S18		1.3				0.2	9.4							3.1
S20		1.2					9.6							3.6
S23						5.9								
S24		0.9			5.1				2.0					3.2
B1	5.3	15.1		0.8	17.0				20.3	11.9		6.9		16.9
B2		8.8	4.2	16.6		1.7						3.4	1.3	12.1
B3			13.6	19.3								9.0	0.8	15.3
B4													7.1	13.1
B5													5.4	
B9		8.4			12.7	11.8	1.1	12.9	9.4	6.1		4.3		12.0
B10	3.1	11.5		1.2	15.3	9.3	0.0		11.3	10.0		3.1		11.8
B11				7.3										1.4
B12	2.8	11.2	8.6	20.5		0.7						3.5	3.5	12.2
B13		10.2	5.5	16.6								0.0	1.2	8.7
B14	3.3	0.0		5.1									5.5	4.2
B15				0.9									7.3	13.2
B16													5.2	1.3
B19		0.5				17.6	8.5				3.5			2.8
B22						1.3								
B23	5.7	14.7				9.9	21.4					6.5		16.3
B24						2.6	3.9							
B25						23.1	6.5							0.7
B26		8.8				11.1	17.2					6.3		11.3
B27		6.8				7.8	15.4							9.3
B28						5.2	8.0							2.1
B29						1.7	2.6							
B30						1.2								
B32						7.4								
M3		5.4		2.5	9.2	7.6			6.2	3.4				6.3
M4	2.9		4.7	15.8								1.6		10.5
M5						5.0	7.9							2.1
C1		6.5	8.7	17.3		0.2						0.7	1.0	8.9
C2	5.1	0.3		5.4									7.7	

*These operations take place during nighttime hours, with exceedances in amount above the 66 dBA nighttime noise limit. All other exceedances are amounts above the 75 dBA daytime noise limit.

8. CONSTRUCTION VIBRATION PREDICTIONS

8.1 Prediction Methodology

Construction vibration levels are predicted using methodologies describe in the Caltrans and FTA Noise and Vibration Guidance Manuals[*]. The vibration model is based on a combination of previous works including measured equipment vibration emission data from the FTA and the Central Artery/Tunnel project in Boston, and ground transmissibility relationships found in Charles Dowding's reference textbook Construction Vibrations[†]. The fundamental equation used in the model is based on propagation relationships of vibration through average soil conditions and distance, as follows:

$$\mathrm{PPV_{receiver}} = \mathrm{PPV_{ref}} * \left(\frac{25}{\mathrm{D}}\right)^{\mathrm{n}}$$

where:

$\mathrm{PPV_{receiver}}$ = predicted PPV at the receiver,

$\mathrm{PPV_{ref}}$ = reference PPV of equipment at 25 feet,

D = distance from the receiver to the equipment in feet

n = 1.5 (the vibration attenuation rate through the soil),

The suggested value for n in the FTA Manual is 1.5 while in the Caltrans Manual it is 1.1. The value for n can lie between 1.0 and 2.0 and a value of 1.5 is commonly used in general models unless detailed information on the local soil conditions are known. The value of 1.5 is considered appropriate for this study.

Equipment vibration emission levels, shown in Table 6, used for the predictions were gathered from measurements performed and published from several projects including the FTA Guidance Manual, Central Artery/Tunnel Project in Boston, and Dowding's textbook.

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[*] *Transit Noise and Vibration Impact Assessment*, Federal Transit Administration: FTA-VA-90-1003-06, May 2006

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

Table 6: Construction Equipment Vibration Reference Levels

Equipment Description		Ref PPV at 25 ft (in/sec)	Minimum Distance for No Impact[1] (ft)
Pile Driver (Impact)	upper range	1.518	52
	typical	0.644	30
Pile Driver (Vibratory)	upper range	0.734	32
	typical	0.170	12
Vibratory Roller		0.210	14
Compactor (Ground)		0.178	13
Large Bulldozer		0.089	8

[1] Distance where the vibrations from the equipment fall below the impact threshold of 0.5 in/sec PPV.

8.2 Construction Vibration Predictions

As shown in Table 6, most equipment does not risk exceeding the vibration limit of 0.5 in/sec PPV until it is very close to the structure. Due to this, no damage risk is expected for many pieces of equipment used in this project. For instance, at their closest, soil rollers are expected to operate 35 feet from the nearest structure. This is well outside the 14 feet minimum distance shown in Table 6 and therefore, no impacts are expected from rollers regardless if they are vibratory or not. Soil compactors are expected to be used as close as 15 feet from buildings during operations 8 and 9, but again this is outside the minimum distance for no impact. However, pile driving is expected in areas close enough to risk exceeding impact levels if high-energy impact pile driving is used. Table 7 shows the predicted vibration levels at receivers that are in close proximity to piling activities. Predictions for the pile driving have used the “upper range” reference levels, since the specific impact equipment and expected hammer energies are not known. For driving sheet piles approximately 30 feet long, which are not intended to support large structural loads, it is unlikely that pile driving vibrations will approach the “upper range” reference levels given in Table 6, however it is conservatively used here to identify a worst case scenario in terms of vibratory impacts.

Table 7: Predicted Vibration Levels from Impact Pile Driving

Receiver ID	Operation	Source to Receiver Distance (ft)	Expected Level[1] (in/sec)
B2	Op4	35	0.916
B3	Op4	35	0.916
B12	Op4	40	0.750
B13	Op4	40	0.750
B14	Op4	45	0.629
M4	Op4	40	0.750
C1	Op4	35	0.916
B1	Op5	40	0.750
B9	Op5	40	0.750
B10	Op5	40	0.750
B26	Op6[2]	45	0.629
B27	Op6[2]	55	0.465

[1] Operations use the upper range impact pile driver for the reference level.
[2] Operation 6 takes place at night

9. CONTROL MEASURES

9.1 Noise Control Measures

The predictions in Table 5 show that all of the construction operations are expected to produce at least some exceedances of the noise limits if no mitigation measures are put in place. The following are noise mitigation measures that can be implemented to reduce the impact to the surrounding community during construction activities:

9.1.1 General Noise Control Measures

- Readily visible signs indicating “Noise Control Zone” would be prepared
- Noise-control devices that meet original specifications and performance would be used
- Electrically-powered equipment would be used to the extent practical.
- Temporary noise barriers and sound-control curtains would be erected where project activity is unavoidably close to noise-sensitive receivers.
- Designated haul routes would be used based on the least overall noise impact route, with heavily-loaded trucks away from residential streets, if possible. Identification of haul routes would consider streets with the fewest noise sensitive receivers if no alternatives are available.
- Earth-moving equipment, fixed noise-generating equipment, stockpiles, staging areas, and other noise-producing operations would be located as far as practicable from noise-sensitive receivers.
- Use of horns, whistles, alarms, and bells would be limited.

- Demolition, earth moving, and ground impacting operations would be phased so as not to occur in the same time period.
- In the case of nighttime construction, the contractor shall comply with the provisions of the nighttime noise variance issued by the local jurisdictions.
- Conduct periodic noise measurements in accordance with an approved noise monitoring plan, specifying monitoring locations, equipment, procedures, and schedule of measurements and reporting methods to be used

9.1.2 Specific Noise Control Measures

- **Noise Barriers**: Noise from most operations can be effectively mitigated through the use of temporary noise barriers, noise control curtains, and/or noise enclosures. A properly constructed noise barrier 8 feet tall around the respective work sites removes all noise impacts from operations 1, 3, 11, 12, and 13. The same size wall leaves an exceedance of less than 1 dB at a single receiver for operations 8 and 10. A wall 12 feet tall leaves an exceedance of less than 1 dB at receiver B1 for operation 9. Three exceedances would remain for operation 7, but all three are at business structures which are likely unoccupied during the nighttime construction work. Operations 2, 4, 5, 6, and 14 benefit from an 8-foot noise barrier, but without additional mitigation measures noise exceedances would still remain.

  The following noise barrier properties are recommended:

  - Break line of sight from noise source to receiver.
  - Use a frame to secure an appropriate acoustic blanket or paneling.
  - Use a solid material with a minimum surface density of 3 lb/ft^2 or mass-loaded acoustic blankets with at least STC 25.
  - Overlap or seal any gaps in the barriers.

- **Drilled Piles**: Pile driving is the dominant noise source for operations 4, 5, and 6 and a noise barrier is insufficient to eliminate impacts at many nearby receivers. Both vibratory and impact pile driving produce similar noise levels; use of vibratory pile driving may remove vibration impacts but it likely will not change the noise levels. Using drilled piles and an 8-foot noise barrier removes all noise impacts for operations 5 and 6, and leaves a single exceedance of less than 1 dB for operation 4.
- **Shielding with Cross Bracing**: Instead of using sheet piles to retain the walls of excavation, the contractor may excavate the trench and shore up the walls with shields and cross bracing. The heavy equipment that would be used for this method is less noisy than pile driving, and no noise exceedances would be expected for operations 4, 5, and 6 using this method and an 8-foot noise barrier surrounding the site.
- **Piling Noise Enclosures**: The use of a noise enclosure specifically around the pile driver and pile may reduce the noise to acceptable levels, though not necessarily eliminate them completely at the closest receivers. Use of these enclosures have shown that they may provide up 10 dB of noise reduction if properly designed and constructed. Some pile driving equipment manufactures may provide factory installed noise suppression systems.
- **Backup Alarms**: It is recommended that low impact backup alarms be used during nighttime hours. Examples of such alarms are white sound, broadband or multi-frequency type devices.

- **Pavement Grinding**: As part of operations 2 and 14, traffic striping on Washington Boulevard will be removed. This is typically done via sandblasting or pavement grinding, both of which are loud activities. Grinding is the quieter of those two options, and would reduce the noise at receivers compared to sandblasting but exceedances would still remain. A movable noise barrier at least 8-feet tall or an acoustically attenuating shield on the equipment would help further reduce the noise to acceptable levels.

9.2 Vibration Control Measures

Vibration caused by pile driving may risk exceeding the damage criteria of 0.5 in/sec PPV at some nearby buildings. Generally, large vibration producing equipment should be place as far as is feasible from vibration sensitive receivers, with special attention to nighttime work and residential receivers. Below are options for reducing vibration levels due to construction activities:

- **Sonic Pile Driving**: At the upper range reference vibration for the sonic/vibratory pile driver, the risk for damage to nearby buildings begins when the equipment is 32 feet or closer to the structure. The nearest piling is expected to be 35 feet from the closest structure, so a vibratory pile driver would remove all vibration limit exceedances. However, noise impacts would remain with this equipment.
- **Dilled Piles**: Noise emission levels from bored/drilled pilling methods are approximately 15 dB lower and PPV levels may be more than 15 times lower than those due to traditional impact piling. The use of these methods will eliminate the vibration impacts of all receivers. These methods will also substantially reduce the noise impacts and in most cases they will also be eliminated, with the use of a suitable noise barrier.
- **Hammer Energy:** A straightforward way to reduce PPV is to lower the hammer energy since there is a direct relationship between hammer energy and the resultant ground vibration. Ground PPV generally follows a square root relationship with hammer energy (i.e. PPV ~ $\sqrt{\text{Hammer Energy}}$). The degree of hammer energy reduction must be balanced against the likelihood/severity of expected exceedances, increase in total driving time, and ability to drive to required friction tolerances.

These additional measures are also recommended:

- **Pre-construction Survey**: A before and after survey should include inspecting building foundations and taking photographs (or installing crack monitors) of pre-existing conditions, cracks, or other flaws. The survey can be limited to buildings closest to the pile driving activities, except for the case of unusually fragile or historic structures that are located within approximately 200 feet of construction. No historic structures were found within the 200-foot screening distance to work sites. However, the Lind Building at 13323 W. Washington Boulevard is of a unique architecture (though of modern construction) and sits directly in front of the piling that will occur during operation 4.

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

  1. Cracks are caused by a variety of construction defects.
  2. Homes contain numerous cracks (of which the owner is unaware) that increase in number and size each year without construction vibration. Vibration that is perceived to

be detrimental to a homeowner's property can cause them to inspect their home more carefully causing them to find cracks they believe are new, yet pre-date the construction activities.

3. These cracks are predominately cosmetic and are not structurally harmful.
4. Slamming doors and passing traffic may vibrate homes more than pile driving does.
5. Human beings are far more sensitive to noise and vibration than are structures.

- **Vibration Monitoring**: It is recommended that vibration monitoring be conducted at any building where equipment is operating closer than the limits listed in Table 6.

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

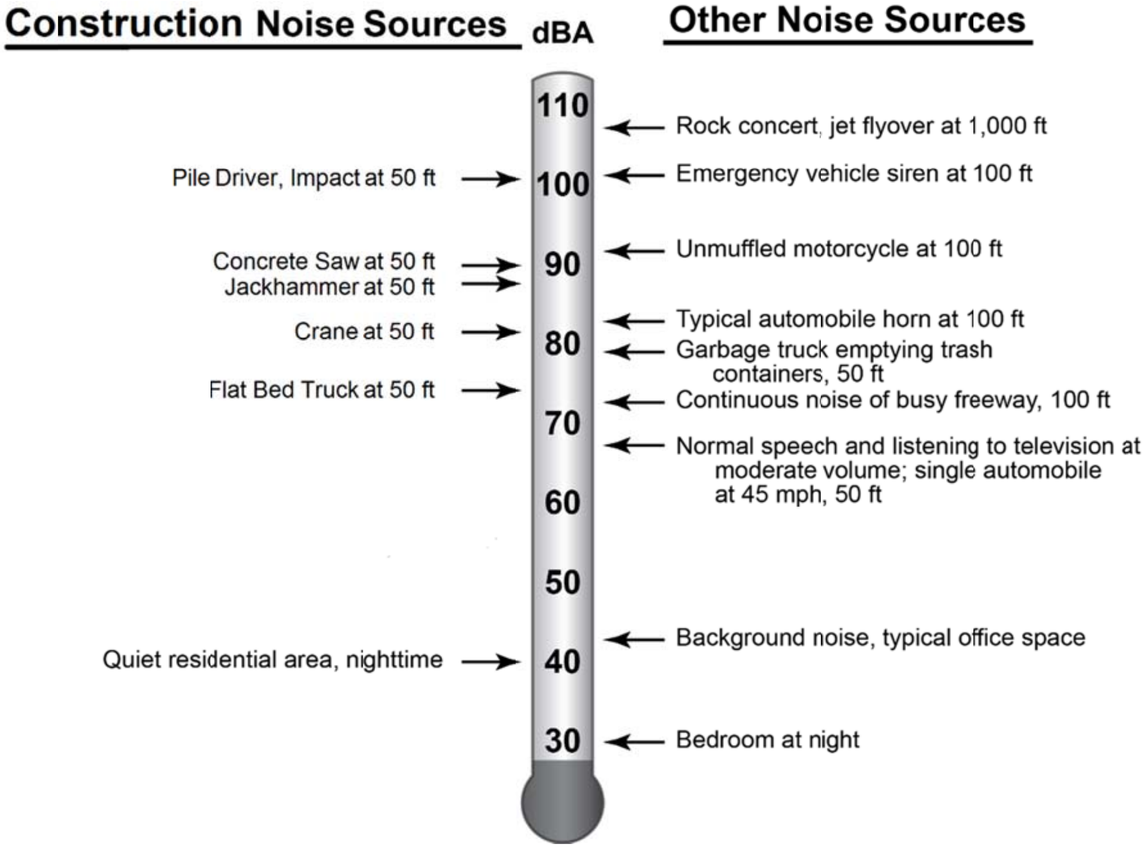

Figure A-4: Typical Outdoor and Indoor Noise Levels

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.
- **Day-Night Sound Level (Ldn)**: Ldn is basically a 24-hour Leq with an adjustment to reflect the greater sensitivity of most people to nighttime noise. The adjustment is a 10-dB penalty for all sound that occurs between the hours of 10 P.M. and 7 A.M. The effect of the penalty is that, when calculating Ldn, any event that occurs during the nighttime is equivalent to 10 of the same event during the daytime. Ldn is the most common measure of total community noise over a 24-hour period.
- **Maximum Sound Level (Lmax)**: The maximum sound level over a period of time or for a specific event can also be a useful parameter for characterizing specific noise sources. Standard sound level meters have two settings, fast and slow, which represent different time constants. Lmax using the fast setting will typically be 1 to 3 dB greater than Lmax using the slow setting.
- **Percent Exceedance Level (Lxx)**: This is the sound level that is exceeded for xx percent of the measurement period. For example, L99 is the sound level exceeded 99 percent of the measurement period. For a one-hour period, the sound level is less than L99 for 36 seconds of the hour and the sound level is greater than L1 for 36 seconds of the hour. L1 represents typical maximum sound levels, L33 is approximately equal to Leq when free-flowing traffic is the dominant noise source, L50 is the median sound level, and L99 is close to the minimum sound level.
- **Sound Exposure Level (SEL)**: SEL is a measure of the total sound energy of an event. In essence, all sound from the event is compressed into a one-second period. This means that SEL increases as the event duration increases and as the event sound level increases.

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 $2^{1/3}$:1 (1.26:1). An octave consists of three 1/3 octaves.

The 1/3-octave band spectrum of a signal is obtained by passing the signal through a bank of filters. Each filter excludes all components except those that are between the upper and lower range of one 1/3-octave band. The FTA Guidance Manual is a good reference for additional information on transit noise and vibration and the technical terms used in this section.