ILLINGWORTH & RODKIN, INC.
Acoustics • Air Quality
1 Willowbrook Court, Suite 120
Petaluma, CA 94954

Memo

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To: John M. Hesler
David J. Powers & Associates, Inc.
1871 The Alameda, Suite 200
San José, CA 95126

From: Dana Lodico, PE, INCE Bd. Cert.
Senior Consultant
Illingworth & Rodkin, Inc.

Subject: **Highway 101/Adobe Creek Overcrossing, Palo Alto, CA – Construction Noise Assessment of Revised Project**

This memo presents the results of the construction noise and vibration assessment completed for the Highway 101 Overcrossing and Reach Trail project at Adobe Creek/Palo Alto Baylands in Palo Alto, California. The proposed project would build a year-round pedestrian/bicycle overcrossing, which would replace the existing seasonal underpass prone to closures. In addition, a Class I multi-use trail would be developed along existing Santa Clara Valley Water District (SCVWD) maintenance facilities. This memo provides an evaluation of noise and vibration levels resulting from project construction activities and recommends measures to reduce construction noise levels. Appendix A presents the fundamentals of environmental noise and vibration for those who may not be familiar with acoustical terminology and/or concepts.

Existing Noise Levels

A site visit and noise monitoring survey were conducted on May 8, 2014 to identify noise and vibration sensitive uses and quantify ambient noise levels in the area. The noise monitoring survey included four short-term (5 to 10 minute duration) measurements, as indicated in Figure 1. Noise levels are summarized in Table 1. Traffic noise from vehicles on Highway 101 was the primary noise sources at all locations.

TABLE 1 Summary of Noise Monitoring Survey

Location (Date, Start Time)	L_{eq}, dBA	L_1, dBA	Primary Noise Source
ST-1: 3801 East Bayshore Road (5/8/14, 11:50am)	63	67	Highway 101 Traffic
ST-2: 3457 Kenneth Drive (5/8/14, 12:15pm)	48	55	Highway 101 Traffic
ST-3: Paloma Townhomes Common Area (5/8/14, 12:30pm)	59	63	Highway 101 Traffic
ST-4: 270 feet west of Hwy 101 (5/8/14, 12:45pm)	61	65	Highway 101 Traffic

Figure 1: Noise Measurement Locations

Construction and Phasing

The proposed project consists of the construction of a year-round, grade-separated, shared bicycle and pedestrian bridge over U.S. 101 and East and West Bayshore Roads at Adobe Creek; construction of sidewalk and bikeway improvements along West Bayshore Road; and construction of an approximately 800-foot long trail along the east side of Adobe Creek between U.S. 101 and East Meadow Drive. Based on preliminary geotechnical recommendations, the bridges would be supported on cast-in-drilled-holes (CIDH) piles that would likely extend to a depth of up to approximately 75 feet. Pile driving is not proposed.

Major construction phases are anticipated to include:

- Site preparation and utility relocation work in advance of the primary bridge construction.

- Principal Span substructure construction (piles, pile caps and pier walls) within the Caltrans right-of-way. This stage would be expedited to minimize impacts to the traveling public.

- East Approach Structure and West Approach Structure construction (including construction of the Adobe Creek Bridge). Work within the banks of Adobe and Barron Creeks, if any, would be limited to between April 15 and October 15.

- Placement of the Principal Span prefabricated steel superstructure over U.S. 101. This would require up to 3 days of night work for temporary closure of U.S. 101 during setting of the Principal Span.

- Adobe Creek Reach Trail Construction. This work would be scheduled to minimize impacts to SCVWD operations.

The City has identified an equipment staging/materials storage area that would be utilized by the contractor during construction. The site is a nearby, City-owned, parcel on the west side of San Antonio Road, just north of U.S. 101, near the San Antonio Road/Casey Street intersection. The area to be used for staging is a gravel lot that is presently used for equipment storage and vehicle parking.

Project construction is anticipated to take roughly 18 months.

Construction Noise Assessment

Regulatory Noise Criteria

Caltrans Standard Specifications, or any special requirements developed during the project design phase, would regulate noise from project construction activities. Section 14-8.02 (Noise Control) of the Caltrans Standard Specifications states:

- Do not exceed 86 dBA at 50 feet from the job site activities from 9:00 p.m. to 6:00 a.m. Use an alternative warning method instead of a sound signal unless required by safety laws.

- Equip an internal combustion engine with the manufacturer-recommended muffler. Do not operate an internal combustion engine on the job site without the appropriate muffler.

Typically, work taking place within the Caltrans right-of-way is not subject to local noise ordinances; however, Caltrans will work with the contractor to meet local requirements where feasible. The City of Palo Alto establishes the following noise limits for construction activities in Section 9.10.060 (Special Provisions) of the Municipal Code:

- Construction is limited to the hours of 8:00 a.m. and 6:00 p.m. on Monday through Friday, 9:00 a.m. and 6:00 p.m. on Saturdays, with unauthorized construction activities prohibited on Sundays and Holidays.

- No individual piece of equipment shall produce a noise level exceeding 110 dBA at a distance of 25 feet. If the device is housed within a structure on the property, the measurement shall be made outside the structure at a distance as close to 25 feet from the equipment as possible.

- The noise level at any point outside of the property plane of the project shall not exceed 110 dBA.

Neither Caltrans nor the City of Palo Alto define a temporary noise increase limit for construction. Temporary noise increases, such as those resulting from project construction activities, are treated somewhat differently than operational noise sources because the increase is not permanent. Following standard practice, the threshold for significance for a short-term noise impact would be exceeded if construction noise levels exceeded 60 dBA L_{eq} and the ambient by 5 dBA L_{eq} or more for a period of more than 12 months at residential use areas.

<u>Construction Noise Levels</u>

Noise generated by project-related construction activities would be a function of the noise levels generated by individual pieces of construction equipment, the type and amount of equipment operating at any given time, the timing and duration of construction activities, the proximity of nearby sensitive land uses, and the presence or lack of shielding at these sensitive land uses. Construction noise levels would vary on a day-to-day basis during each phase of construction depending on the specific task being completed. Each construction phase would require a different combination of construction equipment necessary to complete the task and differing usage factors for such equipment. Construction noise would primarily result from the operation of heavy construction equipment and the arrival and departure of heavy-duty trucks. The bridges would be supported on cast-in-drilled-holes (CIDH) piles. Pile driving is not proposed.

Typical construction noise levels at a distance of 50 feet are shown in Tables 2 and 3. Table 2 shows the average noise level range by construction phase and Table 3 shows the maximum noise level range for different construction equipment. Table 3 levels are consistent with construction noise levels calculated for the project in the Federal Highway Administration Roadway Construction Noise Model, including the anticipated equipment that would be used for each phase of the project. Most demolition and construction noise is in the range of 80 to 90 dBA at a distance of 50 feet from the source.

TABLE 2 Typical Ranges of Construction Noise Levels at 50 Feet, dBA L_{eq}

	Domestic Housing		Office Building, Hotel, Hospital, School, Public Works		Industrial Parking Garage, Religious Amusement & Recreations, Store, Service Station		Public Works Roads & Highways, Sewers, and Trenches	
	I	**II**	**I**	**II**	**I**	**II**	I	II
Ground Clearing	83	83	84	84	84	83	84	84
Excavation	88	75	89	79	89	71	88	78
Foundations	81	81	78	78	77	77	88	88
Erection	81	65	87	75	84	72	79	78
Finishing	88	72	89	75	89	74	84	84

I - All pertinent equipment present at site,
II - Minimum required equipment present at site.

Source: U.S. EPA., Legal Compilation on Noise, Vol. 1, p. 2-104, 1973.

TABLE 3 Construction Equipment 50-foot Noise Emission Limits

Equipment Category	L_{max} Level (dBA)[1,2]	Impact/Continuous
Arc Welder	73	Continuous
Auger Drill Rig	85	Continuous
Backhoe	80	Continuous
Bar Bender	80	Continuous
Boring Jack Power Unit	80	Continuous
Chain Saw	85	Continuous
Compressor[3]	70	Continuous
Compressor (other)	80	Continuous
Concrete Mixer	85	Continuous
Concrete Pump	82	Continuous
Concrete Saw	90	Continuous
Concrete Vibrator	80	Continuous
Crane	85	Continuous
Dozer	85	Continuous
Excavator	85	Continuous
Front End Loader	80	Continuous
Generator	82	Continuous
Generator (25 KVA or less)	70	Continuous
Gradall	85	Continuous
Grader	85	Continuous
Grinder Saw	85	Continuous
Horizontal Boring Hydro Jack	80	Continuous
Hydra Break Ram	90	Impact
Impact Pile Driver	105	Impact
Insitu Soil Sampling Rig	84	Continuous
Jackhammer	85	Impact
Mounted Impact Hammer (hoe ram)	90	Impact
Paver	85	Continuous
Pneumatic Tools	85	Continuous
Pumps	77	Continuous
Rock Drill	85	Continuous
Scraper	85	Continuous
Slurry Trenching Machine	82	Continuous
Soil Mix Drill Rig	80	Continuous
Street Sweeper	80	Continuous
Tractor	84	Continuous
Truck (dump, delivery)	84	Continuous
Vacuum Excavator Truck (vac-truck)	85	Continuous
Vibratory Compactor	80	Continuous
Vibratory Pile Driver	95	Continuous
All other equipment with engines larger than 5 HP	85	Continuous

Source: Noise level outputs from the Federal Highway Administration Roadway Construction Noise Model.

Notes:

1 Measured at 50 feet from the construction equipment, with a "slow" (1 sec.) time constant.

2 Noise limits apply to total noise emitted from equipment and associated components operating at full power while engaged in its intended operation.

3 Portable Air Compressor rated at 75 cfm or greater and that operates at greater than 50 psi.

Demolition, earthwork, and structures would be anticipated to generate hourly average noise levels of 73 to 82 dBA L_{eq} with maximum noise levels reaching about 84 dBA L_{max} at a distance of 100 feet. Construction generated noise levels drop off at a rate of about 6 dBA per doubling of distance between the source and receptor.

The majority of construction activity would occur within the hours specified by the City of Palo Alto's Municipal Code (8:00 a.m. and 6:00 p.m. on Monday through Friday, 9:00 a.m. and 6:00 p.m. on Saturdays). Nighttime construction is anticipated to occur for up to three nights for cranes to lower prefabricated structures in place over West Bayshore Road and East Bayshore Road. Educational and commercial uses are assumed to be daytime uses and would, therefore, not be impacted by nighttime construction work.

Residential Land Uses- Daytime Construction

Residential uses in the vicinity of the project include townhomes located along Paloma Street and single family homes located along Kenneth Drive, located 300 feet and 900 feet west of the project site, respectfully. At a distance of 300 feet, demolition, earthwork, and construction of structures would generate hourly average noise levels of 63 to 72 dBA L_{eq} with maximum instantaneous noise levels reaching 74 dBA L_{max}, not taking into account shielding from intervening structures or terrain. Hourly average construction noise levels at about 900 feet from construction would be 54 to 63 dBA L_{eq}, with maximum instantaneous noise levels reaching 65 dBA L_{max}, again not taking into account shielding from intervening structures or terrain. Both the townhomes located along Paloma Street and the homes along Kenneth Drive would be shielded from construction by existing structures. Shielding from intervening buildings is anticipated to provide an additional 10 to 20 dB of noise reduction at these residences. Assuming 10 dB of noise reduction due to shielding, construction activities are calculated to generate noise levels of 53 to 62 dBA L_{eq} at the Paloma Street townhomes and 44 to 53 dBA L_{eq} at the Kenneth Drive homes. At times when these activities occur further from residences, noise levels would be lower.

The existing ambient daytime noise level at these residences were measured to be about 48 dBA L_{eq} at 3457 Kenneth Drive (with full view of Highway 101) and 59 dBA L_{eq} at the outdoor use area for the Paloma Street townhomes. Construction noise could occasionally exceed existing daytime ambient noise levels at these locations by 3 to 5 dB, but would not typically exceed 60 dBA L_{eq} at residences. Construction activities would generate noise levels below the Caltrans and local daytime criteria.

Residential Land Uses- Nighttime Construction

Nighttime construction work is anticipated to occur over a period of up to three nights for cranes to lower prefabricated structures in place over West Bayshore Road and East Bayshore Road. Based on calculations in the Federal Highway Administration's Roadway Construction Noise Model, these nighttime activities are anticipated to generate an average noise level of 75 dBA L_{eq} at a distance of 100 feet, with maximum instantaneous noise levels also reaching 75 dBA L_{max}.

Residential occupants are typically more sensitive to nighttime construction noise because ambient levels are lower and intermittent noise can cause sleep disturbance. Following standard practice, the threshold for sleep interference is considered to be 35 dBA L_{eq} and 30 dBA L_{max}[1] inside bedrooms. Interior noise levels would vary depending on the final design of the buildings (relative window area to

[1] *Kryter Karl D., The effects of Noise on Man, Second Edition, Academic Press, Inc. London, 1985, p.444-446.*

wall area) and construction materials and methods. Standard residential construction provides approximately 15 dBA of exterior to interior noise reduction assuming the windows are partially open for ventilation. Standard construction with the windows closed provides approximately 20 to 25 dBA of noise reduction in interior spaces. Sleep interference is, therefore, possible when nighttime exterior noise levels are about 50 dBA L_{eq} with open windows and 55 to 60 dBA L_{eq} if the windows are closed. In addition, sleep interference could occur with intermittent instantaneous maximum noise exterior levels greater than 55 dBA L_{max} with open windows and 60 to 65 dBA L_{max} if the windows are closed.

Again, residential uses in the vicinity of the project include single family homes located along Kenneth Drive and townhomes located along Paloma Street. The closest nighttime construction would occur more than 900 feet from the homes on Kenneth Drive and as close as 300 feet from the nearest townhomes along Palomo Street. Shielding from intervening buildings could provide 10 to 20 dB of noise reduction at these residences. Assuming a noise reduction of 10 dB due to intervening structures, nighttime construction activities are calculated to generate noise levels of 46 dBA L_{eq} outside the nearest Kenneth Drive residences and 55 dBA L_{eq} outside the nearest Paloma Street townhomes. Maximum noise levels are anticipated to reach about 46 dBA L_{max} outside the nearest Kenneth Drive residences and 55 dBA L_{max} outside the nearest Paloma Street townhomes. These nighttime construction noise levels would be below the threshold for sleep disturbance at the Kenneth Drive homes with windows in the open or shut position and would be below the threshold for sleep disturbance at the Paloma Street townhomes with windows in the closed position. The Paloma Street townhomes have been confirmed to be installed with mechanical ventilation/central air conditioning, allowing occupants the option of keeping windows closed to control noise.

Educational Land Uses
At the Google Children's Center and at the Pinewood School Activity Center, located as close as 350 feet from the nearest construction activities. Noise generated during demolition, earthwork, and construction of structures would typically generate hourly average noise levels of 62 to 71 dBA L_{eq} and maximum instantaneous noise levels of 73 dBA L_{max} when construction is located nearest the receptors. Again, this does not take shielding from intervening structures or terrain into account. The existing ambient daytime noise level is calculated to be about 54 dBA L_{eq} at Google Children's Center and about 61 dBA L_{eq} at Pinewood School Activity Center. Similar to the discussion above, construction activities would generate noise levels below the Caltrans and local criteria.

Commercial Land Uses
Some surface paving and civil improvements would take place at a distance of about 50 feet from the closest commercial uses. At this distance, construction noise would reach about 84 dBA L_{eq}. Surface paving activities are only anticipated to occur over a period of about 2 months.

Salt Marsh Harvest Mouse Habitat
Pile driving is not proposed for project construction. Minor grading, vehicle circulation, and minor landscaping activities could take place within 50 feet of the mouse habitat area. Demolition, earthwork, and structures would be anticipated to generate hourly average noise levels of 79 to 88 dBA L_{eq} with maximum noise levels reaching about 90 dBA L_{max} at a distance of 50 feet. Construction generated noise levels drop off at a rate of about 6 dBA per doubling of distance between the source and receptor. There are no construction noise criteria applicable to the Salt Marsh Harvest Mouse.

Construction Vehicle Traffic Noise

Construction-related vehicles traveling to and from the Project site would generate worst-hour noise levels of approximately 57 dBA L_{eq} at a distance of 50 feet from the center of the truck route road assuming that the peak number of trucks expected on any one day would be approximately 8 one-way truck trips per hour and that up to 20 one-way vehicle trips would occur per hour for the construction crew. The truck routes would be limited to non-residential streets and primarily follows existing high traffic volume roadways (Highway 101, San Antonio Road) or roadways directly adjacent to Highway 101 (East and West Bayshore Road, Fabian Way, Middlefield Road). As a result, project construction traffic would not measurably increase noise levels along these roadways.

Construction Noise Reduction Measures

To reduce the potential for noise impacts resulting from project construction, the following measures should be implemented during project construction.

- Noise-generating construction activities should be restricted to the hours of 8:00 a.m. to 6:00 p.m. Monday through Friday and 9:00 a.m. to 6:00 p.m. on Saturdays unless necessary to conduct activities outside of these hours due to nighttime closures of Highway 101. No construction activities should occur on Sundays or holidays. Nighttime work and the use of heavy construction equipment shall be limited to the extent practicable.

- For any planned construction outside permitted hours, Caltrans should notify all property owners within 500 feet of the proposed work at least 1 week in advance of the construction activities, require the contractor to implement a construction noise monitoring program and, if feasible, provide additional mitigation as necessary (in the form of noise control blankets or other temporary noise barriers, etc.) for affected receptors.

- Equip all internal combustion engine driven equipment with intake and exhaust mufflers that are in good condition and appropriate for the equipment.

- Unnecessary idling of internal combustion engines within 100 feet of residences should be strictly prohibited.

- Locate stationary noise generating equipment as far as possible from sensitive receptors when sensitive receptors adjoin or are near a construction project area.

- Utilize "quiet" air compressors and other "quiet" equipment where such technology exists.

- Require all construction equipment to conform to Section 14-8. 02, Noise Control, of the latest Caltrans Standard Specifications.

- The contractor should prepare a detailed construction plan identifying the schedule for major noise-generating construction activities and distribute this plan to adjacent noise-sensitive receptors. The construction plan should also list the construction noise reduction measures identified in this study.

Construction Vibration Assessment

Regulatory Vibration Criteria

For structural damage, the California Department of Transportation recommends a vibration limit of 0. 5 inches/second, peak particle velocity (in/sec, PPV) for buildings structurally sound and designed to modern engineering standards, 0.3 in/sec, PPV for older residential buildings, 0.25 for historic and some old buildings, and a conservative limit of 0.08 in/sec, PPV for ancient buildings or buildings that are documented to be structurally weakened. All buildings in the project vicinity are assumed to be structurally sound, but these buildings may or may not have been designed to modern engineering standards. No ancient buildings or buildings that are documented to be structurally weakened are known to exist in the area.

Construction Vibration Levels

Construction activities are anticipated to include site preparation and utility relocation, Principal Span substructure construction, East Approach Structure and West Approach Structure construction, placement of the Principal Span prefabricated steel superstructure over U.S. 101, and Adobe Creek Reach Trail Construction. Based on preliminary geotechnical recommendations, the bridges would be supported on cast-in-drilled-holes (CIDH) piles. Pile driving is not proposed.

Project construction activities, such as CIDH drilling (see caisson drilling in Table 3), the use of jackhammers, rock drills and other high-power or vibratory tools, and rolling stock equipment (tracked vehicles, compactors, etc.) may generate substantial vibration in the immediate vicinity of the work area. Vibration levels would vary depending on soil conditions, construction methods, and equipment used. Table 3 presents typical vibration levels that could be expected from construction equipment at a distance of 25 feet.

TABLE 3 Vibration Source Levels for Construction Equipment

Equipment		**PPV at 25 ft. (in/sec)**
Pile Driver (Impact)	upper range	1.158
	typical	0.644
Pile Driver (Sonic)	upper range	0.734
	typical	0.170
Clam shovel drop		0.202
Hydromill (slurry wall)	in soil	0.008
	in rock	0.017
Vibratory Roller		0.210
Hoe Ram		0.089
Large bulldozer		0.089
Caisson drilling		0.089
Loaded trucks		0.076
Jackhammer		0.035
Small bulldozer		0.003

Source: Transit Noise and Vibration Impact Assessment, United States Department of Transportation, Federal Transit Agency, Office of Planning and Environment, May 2006.

The closest residential, school, and commercial uses are about 300, 350 and 160 feet from construction activities, respectfully. Vibration levels produced by heavy equipment (vibratory rollers, clam shovel drops) during construction are calculated to be 0.014 in/sec PPV or less at a distance of 300 feet, 0.012 in/sec PPV or less at a distance of 350 feet, and 0.027 in/sec PPV or less at a distance of 160 feet. During periods of surface paving and civil improvements, which would take place as close as about 50 feet from the closest commercial uses, vibration levels produced by heavy equipment (vibratory rollers, clam shovel drops) are calculated to be 0.098 in/sec PPV or less. Vibration levels would be lower at structures located further from the construction and as construction moves away from the outer property lines of the site.

Vibration levels would not approach or exceed the 0.3 in/sec PPV threshold and would not be expected to cause cosmetic or structural damage. At the nearest residences and (Paloma Street townhomes) and school uses, vibration caused by project construction would range from below the perceptible threshold to barely perceptible. At the nearest commercial uses, ground borne vibration levels would range from barely perceptible to distinctly perceptible. Vibration levels could reach levels that are strongly perceptible when located about 50 feet from structures. Although vibration may at times be perceptible and/or annoying to occupants of nearby buildings, this would generally not be considered an impact due to the short duration of events.

At the Salt Marsh Harvest Mouse habitat area, located as close as 50 feet from the nearest construction activities, vibration levels are calculated to reach 0.17 in/sec, PPV. There is no known available data discussing how the Salt Marsh Harvest Mouse responds to groundborne vibration. Without the use of impact or vibratory (sonic) pile driving, hydroacoustic impacts on fish are not anticipated.

This is a less-than-significant impact.

Groundborne Vibration Reduction Measures

None Needed.

APPENDIX A: FUNDAMENTALS OF NOISE AND VIBRATION

Fundamentals of Environmental Noise

Noise may be defined as unwanted sound. Noise is usually objectionable because it is disturbing or annoying. The objectionable nature of sound could be caused by its *pitch* or its loudness. *Pitch* is the height or depth of a tone or sound, depending on the relative rapidity (frequency) of the vibrations by which it is produced. Higher pitched signals sound louder to humans than sounds with a lower pitch. *Loudness* is intensity of sound waves combined with the reception characteristics of the ear. Intensity may be compared with the height of an ocean wave in that it is a measure of the amplitude of the sound wave.

In addition to the concepts of pitch and loudness, there are several noise measurement scales which are used to describe noise in a particular location. A decibel (dB) is a unit of measurement which indicates the relative amplitude of a sound. The zero on the decibel scale is based on the lowest sound level that the healthy, unimpaired human ear can detect. Sound levels in decibels are calculated on a logarithmic basis. An increase of 10 decibels represents a ten-fold increase in acoustic energy, while 20 decibels is 100 times more intense, 30 decibels is 1,000 times more intense, etc. There is a relationship between the subjective noisiness or loudness of a sound and its intensity. Each 10 decibel increase in sound level is perceived as approximately a doubling of loudness over a fairly wide range of intensities. Technical terms are defined in Table A-1.

There are several methods of characterizing sound. The most common in California is the A-weighted sound level or dBA. This scale gives greater weight to the frequencies of sound to which the human ear is most sensitive. Representative outdoor and indoor noise levels in units of dBA are shown in Table A-2. Because sound levels can vary markedly over a short period of time, a method for describing either the average character of the sound or the statistical behavior of the variations must be utilized. Most commonly, environmental sounds are described in terms of an average level that has the same acoustical energy as the summation of all the time-varying events. This energy-equivalent sound/noise descriptor is called L_{eq}. The most common averaging period is hourly, but L_{eq} can describe any series of noise events of arbitrary duration.
The scientific instrument used to measure noise is the sound level meter. Sound level meters can accurately measure environmental noise levels to within about plus or minus 1 dBA. Various computer models are used to predict environmental noise levels from sources, such as roadways and airports. The accuracy of the predicted models depends upon the distance the receptor is from the noise source. Close to the noise source, the models are accurate to within about plus or minus 1 to 2 dBA.

Fundamentals of Groundborne Vibration

Ground vibration consists of rapidly fluctuating motions or waves with an average motion of zero. Several different methods are typically used to quantify vibration amplitude. One method is the Peak Particle Velocity (PPV). The PPV is defined as the maximum instantaneous positive or negative peak of the vibration wave. In this report, a PPV descriptor with units of mm/sec or in/sec is used to evaluate construction generated vibration for building damage and human complaints. Table A-3 displays the reactions of people and the effects on buildings that continuous vibration levels produce.

The annoyance levels shown in Table A-3 should be interpreted with care since vibration may be found to be annoying at much lower levels than those shown, depending on the level of activity or the sensitivity of the individual. To sensitive individuals, vibrations approaching the threshold of perception can be annoying. Low-level vibrations frequently cause irritating secondary vibration, such as a slight rattling of windows, doors or stacked dishes. The rattling sound can give rise to exaggerated vibration complaints, even though there is very little risk of actual structural damage.

Construction activities can cause vibration that varies in intensity depending on several factors. The use of pile driving and vibratory compaction equipment typically generates the highest construction related ground-borne vibration levels. Because of the impulsive nature of such activities, the use of the PPV descriptor has been routinely used to measure and assess ground-borne vibration and almost exclusively to assess the potential of vibration to induce structural damage and the degree of annoyance for humans.

The two primary concerns with construction-induced vibration, the potential to damage a structure and the potential to interfere with the enjoyment of life are evaluated against different vibration limits. Studies have shown that the threshold of perception for average persons is in the range of 0.008 to 0.012 in/sec PPV. Human perception to vibration varies with the individual and is a function of physical setting and the type of vibration. Persons exposed to elevated ambient vibration levels, such as people in an urban environment, may tolerate a higher vibration level.

Structural damage can be classified as cosmetic only, such as minor cracking of building elements, or may threaten the integrity of the building. Safe vibration limits that can be applied to assess the potential for damaging a structure vary by researcher and there is no general consensus as to what amount of vibration may pose a threat for structural damage to the building. Construction-induced vibration that can be detrimental to the building is very rare and has only been observed in instances where the structure is at a high state of disrepair and the construction activity occurs immediately adjacent to the structure.

TABLE A-1 Definition of Acoustical Terms Used in this Report

Term	Definition
Decibel, dB	A unit describing, the amplitude of sound, equal to 20 times the logarithm to the base 10 of the ratio of the pressure of the sound measured to the reference pressure. The reference pressure for air is 20.
Sound Pressure Level	Sound pressure is the sound force per unit area, usually expressed in micro Pascals (or 20 micro Newtons per square meter), where 1 Pascal is the pressure resulting from a force of 1 Newton exerted over an area of 1 square meter. The sound pressure level is expressed in decibels as 20 times the logarithm to the base 10 of the ratio between the pressures exerted by the sound to a reference sound pressure (e. g. , 20 micro Pascals). Sound pressure level is the quantity that is directly measured by a sound level meter.
Frequency, Hz	The number of complete pressure fluctuations per second above and below atmospheric pressure. Normal human hearing is between 20 Hz and 20,000 Hz. Infrasonic sound are below 20 Hz and Ultrasonic sounds are above 20,000 Hz.
A-Weighted Sound Level, dBA	The sound pressure level in decibels as measured on a sound level meter using the A-weighting filter network. The A-weighting filter de-emphasizes the very low and very high frequency components of the sound in a manner similar to the frequency response of the human ear and correlates well with subjective reactions to noise.
Equivalent Noise Level, L_{eq}	The average A-weighted noise level during the measurement period.
L_{max}, L_{min}	The maximum and minimum A-weighted noise level during the measurement period.
L_{01}, L_{10}, L_{50}, L_{90}	The A-weighted noise levels that are exceeded 1%, 10%, 50%, and 90% of the time during the measurement period.
Day/Night Noise Level, L_{dn} or DNL	The average A-weighted noise level during a 24-hour day, obtained after addition of 10 decibels to levels measured in the night between 10:00 pm and 7:00 am.
Community Noise Equivalent Level, CNEL	The average A-weighted noise level during a 24-hour day, obtained after addition of 5 decibels in the evening from 7:00 pm to 10:00 pm and after addition of 10 decibels to sound levels measured in the night between 10:00 pm and 7:00 am.
Ambient Noise Level	The composite of noise from all sources near and far. The normal or existing level of environmental noise at a given location.
Intrusive	That noise which intrudes over and above the existing ambient noise at a given location. The relative intrusiveness of a sound depends upon its amplitude, duration, frequency, and time of occurrence and tonal or informational content as well as the prevailing ambient noise level.

Source: Handbook of Acoustical Measurements and Noise Control, Harris, 1998.

TABLE A-2 Typical Noise Levels in the Environment

Common Outdoor Activities	Noise Level (dBA)	Common Indoor Activities
	110 dBA	Rock band
Jet fly-over at 1,000 feet		
	100 dBA	
Gas lawn mower at 3 feet		
	90 dBA	
Diesel truck at 50 feet at 50 mph		Food blender at 3 feet
	80 dBA	Garbage disposal at 3 feet
Noisy urban area, daytime		
Gas lawn mower, 100 feet	70 dBA	Vacuum cleaner at 10 feet
Commercial area		Normal speech at 3 feet
Heavy traffic at 300 feet	60 dBA	
		Large business office
Quiet urban daytime	50 dBA	Dishwasher in next room
Quiet urban nighttime	40 dBA	Theater, large conference room
Quiet suburban nighttime		
	30 dBA	Library
Quiet rural nighttime		Bedroom at night, concert hall (background)
	20 dBA	
		Broadcast/recording studio
	10 dBA	
	0 dBA	

Source: Technical Noise Supplement (TeNS), Caltrans, November 2009.

TABLE A-3 Reaction of People and Damage to Buildings From Continuous or Frequent Intermittent Vibration Levels

Velocity Level, PPV (in/sec)	Human Reaction	Effect on Buildings
0.01	Barely perceptible	No effect
0.04	Distinctly perceptible	Vibration unlikely to cause damage of any type to any structure
0.08	Distinctly perceptible to strongly perceptible	Recommended upper level of the vibration to which ruins and ancient monuments should be subjected
0.1	Strongly perceptible	Virtually no risk of damage to normal buildings
0.3	Strongly perceptible to severe	Threshold at which there is a risk of damage to older residential dwellings such as plastered walls or ceilings
0.5	Severe - Vibrations considered unpleasant	Threshold at which there is a risk of damage to newer residential structures

Source: Transportation- and Construction-Induced Vibration Guidance Manual, California Department of Transportation, June 2004.