Appendix J-1

Noise and Vibration Background

Appendix J. Background on Noise and Ground Vibration

This information was compiled by ICF acoustic analysts to support the Initial Study prepared for the San Francisco-Oakland Bay Bridge Regional Bicycle/Pedestrian Connection Project.

Noise is commonly defined as unwanted sound that annoys or disturbs people and potentially causes an adverse psychological or physiological effect on human health. Because noise is an environmental pollutant that can interfere with human activities, evaluation of noise is necessary when considering the environmental impacts of a Project.

Sound is mechanical energy (vibration) transmitted by pressure waves over a medium such as air or water. Sound is characterized by various parameters that include the rate of oscillation of sound waves (frequency), the speed of propagation, and the pressure level or energy content (amplitude). In particular, the sound pressure level is the most common descriptor used to characterize the loudness of an ambient (existing) sound level. Although the decibel (dB) scale, a logarithmic scale, is used to quantify sound intensity, it does not accurately describe how sound intensity is perceived by human hearing. The human ear is not equally sensitive to all frequencies in the entire spectrum, so noise measurements are weighted more heavily for frequencies to which humans are sensitive in a process called *A-weighting*, written as *dBA* and referred to as *A-weighted decibels*. **Table 1** defines sound measurements and other terminology used in this chapter, and **Table 2** summarizes typical A-weighted sound levels for different noise sources.

In general, human sound perception is such that a change in sound level of 1 dB cannot typically be perceived by the human ear. A change of 3 dB is barely noticeable. A change of 5 dB is clearly noticeable. A change of 10 dB is perceived as doubling or halving the sound level.

Different types of measurements are used to characterize the time-varying nature of sound. These measurements include the equivalent sound level (L_{eq}), the minimum and maximum sound levels (L_{min} and L_{max}), percentile-exceeded sound levels (such as L_{10}, L_{20}), the day-night sound level (L_{dn}), and the community noise equivalent level (CNEL). L_{dn} and CNEL values differ by less than 1 dB. As a matter of practice, L_{dn}

and CNEL values are considered to be equivalent and are treated as such in this assessment.

For a point source such as a stationary compressor or construction equipment, sound attenuates based on geometry at rate of 6 dB per doubling of distance. For a line source such as free flowing traffic on a freeway, sound attenuates at a rate of 3 dB per doubling of distance (California Department of Transportation 2013). Atmospheric conditions including wind, temperature gradients, and humidity can change how sound propagates over distance and can affect the level of sound received at a given location. The degree to which the ground surface absorbs acoustical energy also affects sound propagation. Sound that travels over an acoustically absorptive surface such as grass attenuates at a greater rate than sound that travels over a hard surface such as pavement. The increased attenuation is typically in the range of 1–2 dB per doubling of distance. Barriers such as buildings and topography that block the line of sight between a source and receiver also increase the attenuation of sound over distance.

Table 1. Definition of Sound Measurements

Sound Measurements	Definition
Decibel (dB)	A unitless measure of sound on a logarithmic scale, which indicates the squared ratio of sound pressure amplitude to a reference sound pressure amplitude. The reference pressure is 20 micro-pascals.
A-Weighted Decibel (dBA)	An overall frequency-weighted sound level in decibels that approximates the frequency response of the human ear.
C-Weighted Decibel (dBC)	The sound pressure level in decibels as measured using the C-weighting filter network. The C-weighting is very close to an unweighted or *flat* response. C-weighting is only used in special cases when low-frequency noise is of particular importance. A comparison of measured A- and C-weighted level gives an indication of low frequency content.
Maximum Sound Level (L_{max})	The maximum sound level measured during the measurement period.
Minimum Sound Level (L_{min})	The minimum sound level measured during the measurement period.
Equivalent Sound Level (L_{eq})	The equivalent steady state sound level that in a stated period of time would contain the same acoustical energy.
Percentile-Exceeded Sound Level (L_{xx})	The sound level exceeded *xx* % of a specific time period. L_{10} is the sound level exceeded 10% of the time. L_{90} is the sound level exceeded 90% of the time. L_{90} is often considered to be representative of the background noise level in a given area.
Day-Night Level (L_{dn})	The energy average of the A-weighted sound levels occurring during a 24-hour period, with 10 dB added to the A-weighted sound levels occurring during the period from 10:00 p.m. to 7:00 a.m.

Sound Measurements	Definition
Community Noise Equivalent Level (CNEL)	The energy average of the A-weighted sound levels occurring during a 24-hour period with 5 dB added to the A-weighted sound levels occurring during the period from 7:00 p.m. to 10:00 p.m. and 10 dB added to the A-weighted sound levels occurring during the period from 10:00 p.m. to 7:00 a.m.
Peak Particle Velocity (Peak Velocity or PPV)	A measurement of ground vibration defined as the maximum speed (measured in inches per second) at which a particle in the ground is moving relative to its inactive state. PPV is usually expressed in inches/second.
Frequency: Hertz (Hz)	The number of complete pressure fluctuations per second above and below atmospheric pressure.

Table 2. Typical A-weighted Sound Levels

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

Source: California Department of Transportation 2013.

J.1. Decibel Addition

Because decibels are logarithmic units, sound pressure levels cannot be added or subtracted through ordinary arithmetic. On the dB scale, a doubling of sound energy corresponds to a 3-dB increase. In other words, when two identical sources are each producing sound of the same loudness, their combined sound level at a given distance would be 3 dB higher than one source under the same conditions. For example, if one source produces a sound pressure level of 70 dBA, two identical sources would not produce 140 dBA—rather, they would combine to produce 73 dBA. The cumulative sound level of any number of sources can be determined using decibel addition

J.2. Vibration

Operation of heavy construction equipment, particularly pile driving equipment and other impact devices such as pavement breakers, create seismic waves that radiate along the surface of and downward into the ground. These surface waves can be felt as ground vibration. Vibration from operation of this equipment can result in effects ranging from annoyance of people to damage of structures. Variations in geology and distance result in different vibration levels containing different frequencies and displacements. In all cases, vibration amplitudes decrease with increasing distance.

Perceptible groundborne vibration is generally limited to areas within a few hundred feet of construction activities. As seismic waves travel outward from a vibration source, they cause rock and soil particles to oscillate. The actual distance that these particles move is usually only a few ten-thousandths to a few thousandths of an inch. The rate or velocity (in inches per second) at which these particles move is the commonly accepted descriptor of the vibration amplitude, referred to as the peak particle velocity (PPV).

Vibration amplitude attenuates over distance and is a complex function of how energy is imparted into the ground and the soil or rock conditions through which the vibration is traveling. The following equation is used to estimate the vibration level at a given distance for typical soil conditions (Federal Transit Administration 2006). PPV_{ref} is the reference PPV at 25 feet from **Table 3**:

$$PPV = PPV_{ref} \text{ x } (25/Distance)^{1.5}$$

Table 3 summarizes typical vibration levels generated by construction equipment at the reference distance of 25 feet and other distances as determined using the attenuation equation above.

Table 3. Vibration Source Levels for Construction Equipment

Equipment	PPV at 25 Feet	PPV at 50 Feet	PPV at 75 Feet	PPV at 100 Feet	PPV at 175 Feet
Pile driver (sonic/vibratory)	0.734	0.2595	0.1413	0.0918	0.0396
Hoe ram or large bulldozer	0.089	0.0315	0.0171	0.0111	0.0048
Loaded trucks	0.076	0.0269	0.0146	0.0095	0.0041
Jackhammer	0.035	0.0124	0.0067	0.0044	0.0019
Small bulldozer	0.003	0.0011	0.0006	0.0004	0.0002

Source: Federal Transit Administration 2006.

Tables 4 and 5 summarize guidelines developed by Caltrans for damage and annoyance potential from transient and continuous vibration that is usually associated with construction activity. Pile driving, which would be required during Project construction, is considered a source of continuous vibration (California Department of Transportation 2004).

Table 4. Guideline Vibration Damage Potential Threshold Criteria

	Maximum PPV (in/sec)	
Structure and Condition	Transient Sources	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: California Department of Transportation 2004.

Note: Transient sources create a single isolated vibration event, such as blasting or drop balls. Continuous/frequent intermittent sources include impact pile drivers, pogo-stick compactors, crack-and-seat equipment, vibratory pile drivers, and vibratory compaction equipment.

Table 5. Guideline Vibration Annoyance Potential Criteria

	Maximum PPV (in/sec)	
Structure and Condition	Transient Sources	Continuous/Frequent Intermittent Sources
Barely perceptible	0.04	0.01
Distinctly perceptible	0.25	0.04
Strongly perceptible	0.9	0.10
Severe	2.0	0.4

Source: California Department of Transportation 2004.

Note: Transient sources create a single isolated vibration event, such as blasting or drop balls. Continuous/frequent intermittent sources include impact pile drivers, pogo-stick compactors, crack-and-seat equipment, vibratory pile drivers, and vibratory compaction equipment.

J.3. References

California Department of Transportation. 2004. *Transportation and Construction-Induced Vibration Guidance Manual*. June. Available: <http://www.dot.ca.gov/hq/env/noise/pub/vibrationmanFINAL.pdf>. Accessed: September 5, 2014.

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