

APPENDIX H

Noise Vibration Calculations

Basis of Environmental Acoustics and Vibration

“Sound” is mechanical energy transmitted by pressure waves through a medium such as air. “Noise” can be defined as unwanted sound. 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 has become the most common descriptor used to characterize the loudness of an ambient sound level. Sound pressure level is measured in decibels (dB), with 0 dB corresponding roughly to the threshold of human hearing and 120–140 dB corresponding to the threshold of pain.

The typical human ear is not equally sensitive to all frequencies of the audible sound spectrum. Therefore, when assessing potential noise impacts, sound is measured using an electronic filter that de-emphasizes the frequencies in a manner corresponding to the human ear's decreased sensitivity to low and extremely high frequencies, instead focusing on the frequency mid-range. This method of frequency weighting is referred to as “A-weighting” and is expressed in units of A-weighted decibels (dBA). All sound pressure levels reported below are A-weighted.

Noise Exposure and Ambient Noise

An individual's noise exposure is a measure of the noise experienced by the individual over a period of time. A noise level is a measure of noise at a given instant in time. However, noise levels rarely persist consistently over a long period of time. In fact, noise varies continuously with time with respect to the contributing sources in the noise environment. Noise is primarily the product of many distant noise sources, which constitute a relatively stable background noise exposure, with the individual contributors unidentifiable. Background noise levels change throughout a typical day, but do so gradually, corresponding with the addition and subtraction of distant noise sources and atmospheric conditions. The addition of short duration single-event noise sources (e.g., aircraft flyovers, motor vehicles, sirens) makes noise constantly variable throughout the day.

These successive additions of sound to the noise environment vary the noise level from instant to instant, requiring the measurement of noise exposure over a period of time to legitimately characterize a noise environment and evaluate noise impacts. This time-varying characteristic of environmental noise is

described using statistical noise descriptors. Different noise descriptors used in this analysis to characterize environmental noise are summarized below:

L_{eq} : The equivalent sound level is used to describe noise over a specified period of time, in terms of a single numerical value. The L_{eq} is the constant sound level that would contain the same acoustic energy as the varying sound level, during the same time period (i.e., the average noise exposure level for the given time period).

L_{max} : The instantaneous maximum noise level measured during the period of interest.

Effects of Noise on People

The effects of noise on people can be placed into three categories:

- Subjective effects of annoyance, nuisance, and dissatisfaction
- Interference with activities such as speech, sleep, and learning
- Physiological effects such as hearing loss or sudden startling

Environmental noise typically produces effects in the first two categories. Workers at industrial plants often experience noise in the last category. There is no completely satisfactory way to measure the subjective effects of noise, or the corresponding reactions of annoyance and dissatisfaction. A wide variation exists in the individual thresholds of annoyance, and different tolerances to noise tend to develop based on an individual's past experiences with noise.

Thus, an important way to predict a human reaction to a new noise environment is the way the new noise compares to the existing noise levels that one has adapted to, which is referred to as the "ambient noise" level. In general, the more a new noise exceeds the previously existing ambient noise level, the less acceptable the new noise will be judged by those hearing it.

Regarding increases in A-weighted noise level, the following relationships occur:

- Except in carefully controlled laboratory experiments, a change of 1 dBA cannot be perceived.
- Outside of the laboratory, a 3 dBA change is considered a just-perceivable difference when the change in noise is perceived but does not cause a human response.

- A change in level of at least 5 dBA is required before any noticeable change in human response would be expected.
- A 10 dBA change is subjectively heard as approximately a doubling in loudness and can cause an adverse response.

These relationships occur in part because of the logarithmic nature of sound and the decibel system. The human ear perceives sound in a nonlinear fashion; hence, the decibel scale was developed. Because the decibel scale is based on logarithms, two noise sources do not combine in a simple additive fashion. Rather, they combine logarithmically. For example, if two identical noise sources produce noise levels of 50 dBA, the combined sound level would be 53 dBA, not 100 dBA. However, where ambient noise levels are high in comparison to a new noise source, there will be a small change in noise levels. For example, when 70.0 dBA ambient noise levels are combined with a 60.0 dBA noise source, the resulting noise level equals 70.4 dBA.

Noise Attenuation

Sound level naturally decreases with more distance from the source. This basic attenuation rate is referred to as the “geometric spreading loss.” The basic rate of geometric spreading loss depends on whether a given noise source can be characterized as a “point source” or a “line source.” Point sources of noise, including stationary mobile sources such as idling vehicles or on-site construction equipment, attenuate (lessen) at a rate of 6.0 dBA per doubling of distance from the source. In many cases, noise attenuation from a point source increases to 7.5 dBA for each doubling of distance as a result of ground absorption and reflective wave canceling. These factors are collectively referred to as “excess ground attenuation.” The basic geometric spreading loss rate is used where the ground surface between a noise source and a receiver is reflective, such as parking lots or a smooth body of water. The excess ground attenuation rate (7.5 dBA per doubling of distance) is used where the ground surface is absorptive, such as soft dirt, grass, or scattered bushes and trees.

Widely distributed noises such as a street with moving vehicles (a “line” source) would typically attenuate at a lower rate of approximately 3.0 dBA for each doubling of distance between the source and the receiver. If the ground surface between source and receiver is absorptive rather than reflective, the nominal rate increases to 4.5 dBA for each doubling of distance. Atmospheric effects, such as wind and temperature gradients, can also influence noise

attenuation rates from both line and point sources of noise. However, unlike ground attenuation, atmospheric effects are constantly changing and difficult to predict.

Vibration

Vibration is an oscillatory motion through a solid medium in which the motion's amplitude can be described in terms of displacement, velocity, or acceleration. Several different methods are used to quantify vibration. The "peak particle velocity" (PPV) is defined as the maximum instantaneous peak of the vibration signal and is typically expressed in units of inches per second (in/sec). The PPV is most frequently used to describe vibration impacts on buildings. The "root mean square amplitude" is most frequently used to describe the effect of vibration on the human body. The root mean square amplitude is defined as the average of the squared amplitude of the signal. Decibel notation, expressed as vibration decibels or VdB, is commonly used to measure root mean square. The decibel notation acts to compress the range of numbers required to describe vibration (FTA 2018). Typically, groundborne vibration generated by human activities attenuates rapidly with distance from the source of the vibration.

Some common sources of groundborne vibration are trains, heavy trucks traveling on rough roads, and construction activities such as blasting, pile driving, and operation of heavy earth-moving equipment. The effects of groundborne vibration include movement of the building floors, rattling of windows, shaking of items on shelves or hanging on walls, and rumbling sounds. In extreme cases, vibration can cause damage to buildings. Building damage is not a factor for most projects, with the occasional exception of blasting and pile driving during construction.

Sensitive Receptors

Human response to noise varies considerably from one individual to another. Effects of noise at various levels can include interference with sleep, concentration, and communication, and can cause stress and hearing loss. Given these effects, some land uses are considered more sensitive to ambient noise levels than others. In general, residences, schools, hotels, hospitals, and nursing homes are considered to be the most sensitive to noise. Places such as churches, libraries, and cemeteries, where people tend to pray, study, and/or

contemplate, are also sensitive to noise. Commercial and industrial uses are considered the least noise-sensitive.

Vibration can be assessed through potential building damage and potential human annoyance. Any type of building would typically be considered sensitive to vibration impact because building damage would be considered a permanent negative effect. Human annoyance effects from groundborne vibration are typically only considered inside occupied buildings, not at exterior areas such as residential yards, parks, or other open spaces. Typically, vibrations that would be considered sensitive to human annoyance caused by groundborne vibration are the same as those considered sensitive to noise impacts, including residences, schools, hospitals, churches, and public libraries. Following the Federal Transit Administration's *Transit Noise and Vibration Impact Assessment*, vibration-sensitive land uses are measured from the nearest location on the project site where vibratory equipment would operate (FTA 2018). The nearest groundborne vibration-sensitive location is the single-family residence 1,255 feet southwest of the Sherman Island work area.

Construction Vibration Analysis

Building Damage and Human Annoyance Assessment

Assess for building damage for each piece of equipment individually. Construction vibration is generally assessed in terms of peak particle velocity (PPV).

Construction Equipment	Ref PPV at 25 feet	Distance to Nearest Receptor	PPV at Nearest Receptor
Clam shovel drop (slurry wall)	0.202	150	0.01374
Loaded Trucks	0.076	150	0.00517
Clam shovel drop (slurry wall)	0.202	1255	0.00057
Loaded Trucks	0.076	1255	0.00021

$$PPV_{\text{equip}} = PPV_{\text{ref}} \times (25/D)^{1.5}$$

where: PPV_{equip} is the peak particle velocity in in/sec of the equipment adjusted for distance to nearest receptor

PPV_{ref} is the reference vibration level in in/sec at 25 feet from Table 7-4 (FTA, 2018; page 184)

D is the distance in feet from the equipment to the nearest receptor

Compare the estimated vibration levels to the construction vibration damage criteria from Table 7-5 (FTA, 2018; page 186).

Human Annoyance Assessment & Interference with Sensitive Uses

Assess for annoyance for each piece of equipment individually. Ground-borne vibration related to human annoyance is related to

Construction Equipment	Ref L_v at 25 feet	Distance to Nearest Receptor	VdB at Nearest Receptor
Clam shovel drop (slurry wall)	94	1255	43.0
Loaded Trucks	86	1255	35.0

$$L_v(D) = L_v(25 \text{ ft}) - 30\log(D/25)$$

For assessment of human annoyance or interference with vibration-sensitive activities within buildings, estimate the vibration level L_v at any distance D from the above equation (Use Table 7-4 (FTA, 2018; page 184) for $L_v(25 \text{ ft})$ and apply the vibration impact criteria for General Assessment in Table 6-3 (page 126) or criteria in Table 6-4 (page 126) for vibration-sensitive uses.

Vibration Levels Generated by Construction Equipment

(from Table 7-4 on page 184 of FTA Transit Noise and Vibration Impact and Assessment Manual, Sep 2018)

Equipment	PPV at 25 ft (in/sec)	RMS Velocity (Vdb)
Pile Driver (impact) - upper range	1.518	112
Pile Driver (impact) - typical	0.644	104
Pile Driver (sonic) - upper range	0.734	105
Pile Driver (sonic) - typical	0.17	93
Clam shovel drop (slurry wall)	0.202	94
Hydromill (slurry wall) - in soil	0.008	66
Hydromill (slurry wall) - in rock	0.017	75
Vibratory Roller	0.21	94
Hoe Ram	0.089	87
Large Bulldozer	0.089	87
Caisson Drilling	0.089	87
Loaded Trucks	0.076	86
Jackhammer	0.035	79
Small Bulldozer	0.003	58