Appendix G. Background Information on Acoustics

Background Information on Acoustics

Sound Terminology

Sound travels through the air as waves of minute air pressure fluctuations caused by some type of vibration. In general, sound waves travel away from the sound source as an expanding spherical surface. The energy contained in a sound wave is consequently spread over an increasing area as it travels away from the source. This results in a decrease in loudness at greater distances from the sound source. The following terms are commonly used in acoustics.

Decibel

Sound-level meters measure the pressure fluctuations caused by sound waves. Because of the ability of the human ear to respond to a wide dynamic range of sound pressure fluctuations, loudness is measured in terms of decibels (dB) on a logarithmic scale. This results in a scale that measures pressure fluctuations in a convenient notation and corresponds to our auditory perception of increasing loudness.

A-Weighted Decibels

Most sounds consist of a broad range of sound frequencies. Because the human ear is not equally sensitive to all frequencies, several frequency-weighting schemes have been used to develop composite decibel scales that approximate the way the human ear responds to sound levels. The “A-weighted” decibel scale (dBA) is the most widely used for this purpose. Typical A-weighted sound levels for various types of sound sources are summarized in Figure G-1.

Equivalent Sound Level

Time-varying sound levels are often described in terms of an equivalent constant decibel level. Equivalent sound levels (L_{eq}) are used to develop single-value descriptions of average sound exposure over various periods of time. Such average sound exposure values often include additional weighting factors for annoyance potential attributable to time of day or other considerations. The L_{eq} data used for these average sound exposure descriptors are generally based on A-weighted sound-level measurements.

Day-Night Average Sound Level

Average sound exposure over a 24-hour period is often presented as a day-night average sound level (L_{dn}). L_{dn} values are calculated from hourly L_{eq} values, with the L_{eq} values for the nighttime period (10:00 p.m.-7:00 a.m.) increased by 10 dB to reflect the greater disturbance potential from nighttime noises.

Community Noise Equivalent Level

The community noise equivalent level (CNEL) is also used to characterize average sound levels over a 24-hour period, with weighting factors included for evening and nighttime sound levels. L_{eq} values for the evening period (7:00 p.m.-10:00 p.m.) are increased by 5 dB, while L_{eq} values for the nighttime period (10:00 p.m.-7:00 a.m.) are increased by 10 dB. For given set of sound measurements, the CNEL value will usually be about 1 dB higher than the L_{dn} value. In practice, CNEL and L_{dn} are often used interchangeably.

Percentile-Exceeded, Maximum, and Minimum Sound Level

The sound level exceeded during a given percentage of a measurement period is the percentile-exceeded sound level (L_x). Examples include L_{10}, L_{50}, and L_{90}. L_{10} is the A-weighted sound level that is exceeded 10% of the measurement period, L_{50} is the level exceeded 50% of the period, and so on. L_{50} is the median sound level measured during the measurement period. $L_{90,}$ the sound level exceeded 90% of the time, excludes high localized sound levels produced by nearby sources such as single car passages or bird chirps. L_{90} is often used to represent the background sound level. L_{50} is also used to provide a less conservative assessment of the background sound level.

The maximum sound level (L_{max}) and the minimum sound level (L_{min}) are the maximum and minimum sound levels respectively, measured during the measurement period. When a sound meter is set to the “slow” response setting as is typical for most community noise measurements, the Lmax and Lmin values are the maximum and minimum levels measured over a one second period.

Sound Source	Sound Level (dBA)*	Response
Carrier deck jet operation	140	
Civil defense siren (at 100 feet)	130	Painfully loud
Jet takeoff (at 200 feet)	120	Threshold of feeling and pain
Riveting machine (at 1 foot) Rock music concert	110	
Pile driver (at 50 feet) Ambulance siren (at 100 feet)	100	Very loud
Heavy truck (at 50 feet)	90	
Pneumatic drill (at 50 feet) Freight train cars (at 50 feet) Garbage disposal in home	80	
Freight train cars (at 100 feet) Freeway traffic (at 50 feet) Vacuum cleaner (at 10 feet)	70	Moderately loud
Air conditioning unit (at 20 feet)	60	
Speech in normal voice (at 15 feet)	50	
Residence-typical movement of people, no TV or radio	40	Quiet
Soft whisper (at 5 feet)	30	
Recording studio	20	
	10	
	0	Threshold of hearing

* Typical A-weighted sound levels in decibels. "A" weighting approximates the frequency response of the human ear.

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Figure G-1
Weighted Sound Levels and Human Response

Ambient Sound

Ambient sound is the all-encompassing sound associated with a given community site, usually being a composite of sounds from many sources, near and far, with no particular sound being dominant.

Equivalencies between Various Sound Descriptors

The L_{dn} value at a site calculated from a set of measurements taken over a given 24-hour period will be slightly lower than the CNEL value calculated over the same period. Except in situations where unusually high evening sound levels occur, the CNEL value will be within 1.5 dB of the L_{dn} value for the same set of sound measurements.

The relationship between peak hourly L_{eq} values and associated L_{dn} values depends on the distribution of traffic over the entire day. There is no precise way to convert a peak hourly L_{eq} value to an L_{dn} value. However, in urban areas near heavy traffic, the peak hourly L_{eq} value is typically 2-4 dB lower than the daily L_{dn} value. In less heavily developed areas, the peak hourly L_{eq} is often equal to the daily L_{dn} value. For rural areas with little nighttime traffic, the peak hourly L_{eq} value will often be 3-4 dB greater than the daily L_{dn} value.

Working with Decibel Values

The nature of the decibel scale is such that the individual sound levels for different sound sources cannot be added directly to give the combined sound level of these sources. Two sound sources producing equal sound levels at a given location will produce a composite sound level that is 3 dB greater than either sound alone. When two sound sources differ by 10 dB, the composite sound level will be only 0.4 dB greater than the louder source alone.

Most people have difficulty distinguishing the louder of two sound sources if they differ by less than 1.5-2.0 dB. Research into the human perception of changes in sound level indicates the following:

- a 3-dB change is just perceptible,
- a 5-dB change is clearly perceptible, and
- a 10-dB change is perceived as being twice or half as loud.

A doubling or halving of acoustic energy will change the resulting sound level by 3 dB, which corresponds to a change that is just perceptible. In practice, this means that a doubling of traffic volume on a roadway, doubling the number of people in a stadium, or doubling the number of wind turbines in a wind farm will, as a general rule, only result in a 3-dB, or just perceptible, increase in noise.

Outdoor Sound Propagation

There are a number of factors that affect how sound propagates outdoors. These factors, described by Hoover and Keith (1996), are summarized below.

Distance Attenuation

As a general rule, sound from localized or point sound sources spreads out as it travels away from the source and the sound level drops at a rate of 6 dB per doubling of distance. If the sound source is long in one dimension, such as traffic on a highway or a long train, the sound source is considered to be a line source. As a general rule, the sound level from a line source will drop off at a rate of 3 dB per doubling of distance. If the intervening ground between the line source and the receptor is acoustically “soft” (e.g., ground vegetation, scattered trees, clumps of bushes), an attenuation rate of 4.5 dB per doubling of distance is generally used.

Attenuation from Barriers

Any solid structure such as a berm, wall, or building that blocks the line of sight between a source and receiver serves as a sound barrier and will result in additional sound attenuation. The amount of additional attenuation is a function of the difference between the length of the sound path over the barrier and the length of the direct line of sight path. Thus, the sound attenuation of a barrier between a source and a receiver that are very far apart will be much less than the attenuation that would result if either the source or the receiver is very close to the barrier.

Molecular Absorption

Air absorbs sound energy as a function of the temperature, humidity of the air, and frequency of the sound. Additional sound attenuation on the order of 1 to 2 dB per 1,000 feet can occur.

Anomalous Excess Attenuation

Large-scale effects of wind speed, wind direction, and thermal gradients in the air can cause large differences in sound transmission over large distances. These effects when combined result in anomalous excess attenuation, which can be applied to long-term sound-level estimates. Additional sound attenuation on the order of about 1 dB per 1,000 feet can occur.

Other Atmospheric Effects

Short-term atmospheric effects relating to wind and temperature gradients can cause bending of sound waves and can influence changes in sound levels at large distances. These effects can either increase or decrease sound levels depending on the orientation of the source and receptor and the nature of the wind and temperature gradient. Because these effects are normally short-term, it is generally not practical to include them in sound propagation calculations. Understanding these effects, however, can help explain variations that occur between calculated and measured sound levels.

Guidelines for Interpreting Sound Levels

Various federal, state, and local agencies have developed guidelines for evaluating land use compatibility under different sound-level ranges. The following is a summary of federal and state guidelines.

Federal Agency Guidelines

The federal Noise Control Act of 1972 (Public Law 92-574) established a requirement that all federal agencies administer their programs to promote an environment free of noise that jeopardizes public health or welfare. The U.S. Environmental Protection Agency (EPA) was given the responsibility for:

- providing information to the public regarding identifiable effects of noise on public health or welfare,
- publishing information on the levels of environmental noise that will protect the public health and welfare with an adequate margin of safety,
- coordinating federal research and activities related to noise control, and
- establishing federal noise emission standards for selected products distributed in interstate commerce.

The federal Noise Control Act also directed that all federal agencies comply with applicable federal, state, interstate, and local noise control regulations.

Although EPA was given major public information and federal agency coordination roles, each federal agency retains authority to adopt noise regulations pertaining to agency programs. EPA can require other federal agencies to justify their noise regulations in terms of the federal Noise Control Act policy requirements. The Occupational Safety and Health Administration retains primary authority for setting workplace noise exposure standards. The Federal Aviation Administration retains primary jurisdiction over aircraft noise standards, and the Federal Highway Administration (FHWA) retains primary jurisdiction over highway noise standards.

In 1974, in response to the requirements of the federal Noise Control Act, EPA identified indoor and outdoor noise limits to protect public health and welfare (communication disruption, sleep disturbance, and hearing damage). Outdoor L_{dn} limits of 55 dB and indoor L_{dn} limits of 45 dB are identified as desirable to protect against speech interference and sleep disturbance for residential, educational, and healthcare areas. Sound-level criteria to protect against hearing damage in commercial and industrial areas are identified as 24-hour L_{eq} values of 70 dB (both outdoors and indoors).

The FHWA has adopted criteria for evaluating noise impacts associated with federally funded highway projects and for determining whether these impacts are sufficient to justify funding noise mitigation actions (23 CFR 772). The FHWA noise abatement criteria are based on peak hourly L_{eq} sound levels, not L_{dn} or 24-hour L_{eq} values. The peak 1-hour L_{eq} criteria for residential, educational, and healthcare facilities are 67 dB outdoors and 52 dB indoors. The peak 1-hour L_{eq} criterion for commercial and industrial areas is 72 dB (outdoors).

The U.S. Department of Housing and Urban Development has established guidelines for evaluating noise impacts on residential projects seeking financial support under various grant programs (44 FR 135:40860-40866, January 23, 1979). Sites are generally considered acceptable for residential use if they are exposed to outdoor L_{dn} values of 65 dB or less. Sites are considered “normally unacceptable” if they are exposed to outdoor L_{dn} values of 65-75 dB. Sites are considered unacceptable if they are exposed to outdoor L_{dn} values above 75 dB.

State Agency Guidelines

In 1987, the California Department of Health Services published guidelines for the noise elements of local general plans. These guidelines include a sound level/land use compatibility chart that categorizes various outdoor L_{dn} ranges into up to four compatibility categories (normally acceptable, conditionally acceptable, normally unacceptable, and clearly unacceptable) by land use. For many land uses, the chart shows overlapping L_{dn} ranges for two or more compatibility categories.

The noise element guidelines chart identifies the normally acceptable range for low-density residential uses as less than 60 dB and the conditionally acceptable range as 55-70 dB. The normally acceptable range for high-density residential uses is identified as L_{dn} values below 65 dB, and the conditionally acceptable range is identified as 60-70 dB. For educational and medical facilities, L_{dn} values below 70 dB are considered normally acceptable and L_{dn} values of 60-70 dB are considered conditionally acceptable. For office and commercial land uses, L_{dn} values below 70 dB are considered normally acceptable and L_{dn} values of 67.5-77.5 are categorized as conditionally acceptable.

These overlapping L_{dn} ranges are intended to indicate that local conditions (existing sound levels and community attitudes toward dominant sound sources) should be considered in evaluating land use compatibility at specific locations.

The California Department of Housing and Community Development has adopted noise insulation performance standards for new hotels, motels, and dwellings other than detached single-family structures (24 CCR T25-28). These standards require that “interior CNELs with windows closed, attributable to exterior sources, shall not exceed an annual CNEL of 45 dB in any habitable room”.

The California Department of Transportation uses the FHWA criteria as the basis for evaluating noise impacts from highway projects.

Reference

Hoover, R. M., and R. H. Keith. 1996. Noise control for buildings and manufacturing plants. Hoover and Keith, Inc. Houston, TX.