12. NOISE AND VIBRATION DURING CONSTRUCTION

Construction often generates community noise/vibration complaints despite the limited time frame over which it takes place. Complaints typically arise from interference with people's activities, especially when the community has no clear understanding of the extent or duration of the construction. Misunderstandings can arise when the contractor is considered to be insensitive by the community even though he believes he is in compliance with local ordinances. This situation underscores the need for early identification and assessment of potential problem areas. An assessment of the potential for complaints can be made by following procedures outlined in this chapter. That assessment can aid contractors in making bids by allowing changes in construction approach and including mitigation costs before the construction plans are finalized. Publication of an assessment including a description of the construction noise and vibration environment can lead to greater understanding and tolerance in the community.

Control of construction noise and vibration occurs in three steps:

1. **Assessment and Reporting:** The environmental impact assessment identifies the potential problem areas during the construction phase of a project and serves to inform the public of the project's construction effects. This is important for new major infrastructure projects where heavy construction can take place over a lengthy period of time.

2. **Construction specifications:** Most large construction projects incorporate noise specifications on construction equipment, but sometimes additional measures are needed to minimize community complaints. Special mitigation measures can be written into the construction documents where necessary as identified by the impact assessment. The documents should include realistic specifications which lessen community annoyance without forcing unreasonable constraints on the contractors.

3. **Compliance verification:** Field inspectors need to be given clear direction on conducting and reporting measurements for compliance with noise specifications in noise-sensitive areas.

12.1 CONSTRUCTION NOISE

The noise levels created by construction equipment will vary greatly depending on factors such as the type of equipment, the specific model, the operation being performed, and the condition of the equipment. The equivalent sound level (L_{eq}) of the construction activity also depends on the fraction of time that the equipment is operated over the time period of construction. This section provides information on typical levels generated by various construction equipment and provides guidance on assessment of noise from the construction activities related to transit facilities. It should be noted that the level of noise analysis should be commensurate with the type and scale of the project, and the presence of noise-sensitive land uses in the construction zone.

12.1.1 Noise from Typical Construction Equipment and Operations

The dominant source of noise from most construction equipment is the engine, usually a diesel, without sufficient muffling. In a few cases, such as impact pile driving or pavement breaking, noise generated by the process dominates. For considerations of noise assessment, construction equipment can be considered to operate in two modes, stationary and mobile. Stationary equipment operates in one location for one or more days at a time, with either a fixed power operation (pumps, generators, compressors) or a variable noise operation (pile drivers, pavement breakers). Mobile equipment moves around the construction site with power applied in cyclic fashion (bulldozers, loaders), or to and from the site (trucks). The movement around the site is handled in the construction noise prediction procedure discussed later in this chapter. Variation in power imposes additional complexity in characterizing the noise source level from a piece of equipment. This is handled by describing the noise at a reference distance from the equipment operating at full power and adjusting it based on the duty cycle of the activity to determine the L_{eq} of the operation. Standardized procedures for measuring the exterior noise levels for the certification of mobile and stationary construction equipment have been developed by the Society of Automotive Engineers.[(1)(2)] Typical noise levels from representative pieces of equipment are listed in Table 12-1.

Construction activities are characterized by variations in the power expended by equipment, with resulting variation in noise levels with time. Variation in the power is expressed in terms of the "usage factor" of the equipment, the percentage of time during the workday that the equipment is operating at full power. Time-varying noise levels are converted to a single number (L_{eq}) for each piece of equipment during the operation. Besides having daily variations in activities, major construction projects are accomplished in several different phases. Each phase has a specific equipment mix depending on the work to be accomplished during that phase.

Each phase has its own noise characteristics; some have higher continuous noise levels than others, some have high impact noise levels. The purpose of the assessment is to determine not only the levels, but also the duration of the noise. The L_{eq} of each phase is determined by combining the L_{eq} contributions from each piece of equipment used in that phase. The impact and the consequent noise mitigation approaches depend on the criteria to be used in assessing impact, as discussed in the next section.

Table 12-1 Construction Equipment Noise Emission Levels

Equipment	Typical Noise Level (dBA) 50 ft from Source
Air Compressor	81
Backhoe	80
Ballast Equalizer	82
Ballast Tamper	83
Compactor	82
Concrete Mixer	85
Concrete Pump	82
Concrete Vibrator	76
Crane, Derrick	88
Crane, Mobile	83
Dozer	85
Generator	81
Grader	85
Impact Wrench	85
Jack Hammer	88
Loader	85
Paver	89
Pile Driver (Impact)	101
---"------ (Sonic)	96
Pneumatic Tool	85
Pump	76
Rail Saw	90
Rock Drill	98
Roller	74
Saw	76
Scarifier	83
Scraper	89
Shovel	82
Spike Driver	77
Tie Cutter	84
Tie Handler	80
Tie Inserter	85
Truck	88

Table based on an EPA Report,(3) measured data from railroad construction equipment taken during the Northeast Corridor Improvement Project(4) and other measured data.(5)(6)

12.1.2 Construction Noise Assessment

The level of detail of a construction noise assessment depends on the scale and the type of project and the stage of environmental review. Where the project is major – the construction duration is expected to last for more than several months, noisy equipment will be involved, or the construction is expected to take place near a noise-sensitive site – then construction noise impacts may be determined in considerable detail, as described in this section. Otherwise, the assessment may simply be a description of the equipment to be used, the duration of construction, and any mitigation requirements placed on particularly noisy operations.

A construction noise assessment for a major project is performed by comparing the predicted noise levels with criteria established for the type of project. The approach requires an appropriate descriptor, a standardized prediction method and a set of recognized criteria for assessing the impact.

The *descriptor* used for construction noise is the L_{eq}. This unit is appropriate for the following reasons:

- It can be used to describe the noise level from operation of each piece of equipment separately and is easy to combine to represent the noise level from all equipment operating during a given period.
- It can be used to describe the noise level during an entire phase.
- It can be used to describe the average noise over all phases of the construction.

The recommended *method* for predicting construction noise impact for major urban transit projects is similar to that suggested by the Federal Highway Administration (FHWA).[7] The FHWA prediction method is used to estimate the construction noise levels associated with the construction of a highway, but it can be used for any transportation project. The method requires:

1. An emission model to determine the noise generated by the equipment at a reference distance.
2. A propagation model that shows how the noise level will vary with distance.
3. A way of summing the noise of each piece of equipment at locations of noise-sensitivity.

The first two components of the model are related by the following equation:

$$L_{eq}(equip) = E.L. + 10\log(U.F.) - 20\log\left(\frac{D}{50}\right) - 10\,G\log\left(\frac{D}{50}\right)$$

where: L_{eq} *(equip)* is the L_{eq} at a receiver resulting from the operation of a single piece of equipment over a specified time period

E.L. is the noise emission level of the particular piece of equipment at the reference distance of 50 feet, taken from Table 12-1

G is a constant that accounts for topography and ground effects, taken from Figure 6-5 (Chapter 6)

D is the distance from the receiver to the piece of equipment, and

U.F. is a usage factor that accounts for the fraction of time that the equipment is in use over the specified time period.

The combination of noise from several pieces of equipment operating during the same time period is obtained from decibel addition of the L_{eq} of each single piece of equipment found from the above equation.

Major Construction Projects

The approach can be as detailed as necessary to characterize the construction noise by specifying the various quantities in the equation. For projects in an early assessment stage when the equipment roster and schedule are undefined, only a rough estimate of construction noise levels is practical.

The following assumptions are adequate for a general assessment of each phase of construction:

1. Full power operation for a time period of one hour is assumed because most construction equipment operates continuously for periods of one hour or more at some point in the construction period. Therefore, U.F. = 1, and 10 log(U.F.) = 0.
2. Free field conditions are assumed and ground effects are ignored. Consequently, G = 0.
3. Emission level at 50 feet, E.L., is taken from Table 12-1.
4. All pieces of equipment are assumed to operate at the center of the project, or centerline, in the case of a guideway or highway construction project.
5. The predictions include only the two noisiest pieces of equipment expected to be used in each construction phase.

A more detailed approach can be used if warranted, such as when a known noise-sensitive site is adjacent to a construction project or where contractors are faced with stringent local ordinances or specifications as a result of public concern. Additional details include:

1. Accounting for the duration of the construction. Long-term construction project noise impact is based on a 30 day average L_{dn}, the times of day of construction activity (nighttime noise is penalized by 10 dB in residential areas), and the percentage of time the equipment is to be used during a period of time which will affect U.F. For example, an 8-hour L_{eq} is determined by making **U.F.** the percentage of time each individual piece of equipment operates under full power in that period. Similarly, the 30-day average L_{dn} is determined from the **U.F.** expressed by the percentage of time the equipment is used during the daytime hours (7 a.m. to 10 p.m.) and nighttime (10 p.m. to 7 a.m.), separately over a 30 day period. However, to account for increased sensitivity to nighttime noise, the nighttime percentage is multiplied by 10 before performing the computation.
2. Taking into account the site topography, natural and man-made barriers and ground effects. This will change the factor G. Use Figure 6-5 (Chapter 6) to calculate G.
3. Measuring or certifying the emission level of each piece of equipment. This will refine E.L.
4. Determining the location of each piece of equipment while it is working. The distance factor D is therefore specified more exactly.

5. Including all pieces of equipment in the computation of the 8-hour L_{eq} and the 30-day average L_{dn}. The total noise levels are determined using Table 6-11 (Chapter 6).

Minor Construction Projects

Most minor projects need no construction noise assessment at all. However, there may be cases involving a limited period of construction time – less than a month in a noise-sensitive area – where there may be a temporary effect where a qualitative treatment is appropriate. Community relations will be important in these cases; early information disseminated to the public about the kinds of equipment, expected noise levels and durations will help to forewarn potentially affected neighbors about the temporary inconvenience. In these cases, a general description of the variation of noise levels during a typical construction day may be helpful. The first method above will be sufficient to provide the estimated noise levels. The criteria suggested below are not applicable in these cases.

Criteria

No standardized *criteria* have been developed for assessing construction noise impact. Consequently, criteria must be developed on a project-specific basis unless local ordinances can be found to apply. Generally, local noise ordinances are not very useful in evaluating construction noise. They usually relate to nuisance and hours of allowed activity and sometimes specify limits in terms of maximum levels, but are generally not practical for assessing the impact of a construction project. Project construction noise criteria should take into account the existing noise environment, the absolute noise levels during construction activities, the duration of the construction, and the adjacent land use. While it is not the purpose of this manual to specify standardized criteria for construction noise impact, the following guidelines can be considered reasonable criteria for assessment. If these criteria are exceeded, there may be adverse community reaction.

General Assessment – Estimate the combined noise level in one hour from the two noisiest pieces of equipment, assuming they both operate at the same time. Then identify locations where the level exceeds the following:

Land Use	One-hour L_{eq} (dBA)	
	Day	Night
Residential	90	80
Commercial	100	100
Industrial	100	100

Detailed Assessment – Predict the noise level in terms of 8-hour L_{eq} and 30-day averaged L_{dn} and compare to criteria in the following table:

Land Use	8-hour L_{eq} (dBA)		L_{dn} (dBA)
	Day	Night	30-day Average
Residential	80	70	75[a]
Commercial	85	85	80[b]
Industrial	90	90	85[b]

(a) In urban areas with very high ambient noise levels (L_{dn} > 65 dB), L_{dn} from construction operations should not exceed existing ambient + 10 dB.

(b) Twenty-four hour L_{eq}, not L_{dn}.

12.1.3 Mitigation of Construction Noise

After using the above approach to locate potential impacts from construction noise, the next step is to identify appropriate control measures. Three categories of noise control approaches, with examples, are given below:

1. *Design considerations and project layout:*

   - Construct noise barriers, such as temporary walls or piles of excavated material, between noisy activities and noise-sensitive receivers.
   - Re-route truck traffic away from residential streets, if possible. Select streets with fewest homes, if no alternatives are available.
   - Site equipment on the construction lot as far away from noise-sensitive sites as possible.
   - Construct walled enclosures around especially noisy activities, or clusters of noisy equipment. For example, shields can be used around pavement breakers, loaded vinyl curtains can be draped under elevated structures .

2. *Sequence of operations:*

   - Combine noisy operations to occur in the same time period. The total noise level produced will not be significantly greater than the level produced if the operations were performed separately.
   - Avoid nighttime activities. Sensitivity to noise increases during the nighttime hours in residential neighborhoods.

3. *Alternative construction methods:*

   - Avoid impact pile driving where possible in noise-sensitive areas. Drilled piles or the use of a sonic or vibratory pile driver are quieter alternatives where the geological conditions permit their use.

- Use specially quieted equipment, such as quieted and enclosed air compressors, mufflers on all engines.
- Select quieter demolition methods, where possible. For example, sawing bridge decks into sections that can be loaded onto trucks results in lower cumulative noise levels than impact demolition by pavement breakers.

The environmental assessment should include description of how each impacted location will be treated with one or more mitigation approaches.

12.2 CONSTRUCTION VIBRATION

Construction activity can result in varying degrees of ground vibration, depending on the equipment and methods employed. Operation of construction equipment causes ground vibrations which spread through the ground and diminish in strength with distance. Buildings founded on the soil in the vicinity of the construction site respond to these vibrations, with varying results ranging from no perceptible effects at the lowest levels, low rumbling sounds and feelable vibrations at moderate levels and slight damage at the highest levels. Ground vibrations from construction activities very rarely reach the levels that can damage structures, but can achieve the audible and feelable ranges in buildings very close to the site. A possible exception is the case of old, fragile buildings of historical significance where special care must be taken to avoid damage. The construction vibration criteria include special consideration for fragile historical buildings. The construction activities that typically generate the most severe vibrations are blasting and impact pile driving.

Vibration levels for construction equipment have been published based on measured data near various types of equipment (see Table 12-2). Since the primary concern with regard to construction vibration is building damage, construction vibration is generally assessed in terms of peak particle velocity (PPV), as defined in Chapter 7.1.2. Peak particle velocity is typically a factor of 1.7 to 6 times greater than root mean square (rms) vibration velocity; a factor of 4 has been used to calculate the approximate rms vibration velocity levels indicated in Table 12-2.

12.2.1 Vibration Source Levels from Construction Equipment

Various types of construction equipment have been measured under a wide variety of construction activities with an average of source levels reported in terms of velocity levels as shown in Table 12-2 . Although the table gives one level for each piece of equipment, it should be noted that there is a considerable variation in reported ground vibration levels from construction activities. The data provide a reasonable estimate for a wide range of soil conditions.

Table 12-2 Vibration Source Levels for Construction Equipment (From measured data.[8][9][10][11])			
Equipment		**PPV at 25 ft (in/sec)**	**Approximate L_v† at 25 ft**
Pile Driver (impact)	upper range	1.518	112
	typical	0.644	104
Pile Driver (sonic)	upper range	0.734	105
	typical	0.170	93
Clam shovel drop (slurry wall)		0.202	94
Hydromill (slurry wall)	in soil	0.008	66
	in rock	0.017	75
Large bulldozer		0.089	87
Caisson drilling		0.089	87
Loaded trucks		0.076	86
Jackhammer		0.035	79
Small bulldozer		0.003	58

† RMS velocity in decibels (VdB) re 1 μinch/second

12.2.2 Construction Vibration Assessment

Construction vibration should be assessed in cases where there is a significant potential for impact from construction activities. Such activities include blasting, pile driving, demolition and drilling or excavation in close proximity to sensitive structures. The recommended procedure for estimating vibration impact from construction activities is as follows:

- Select the equipment and associated vibration source levels at a reference distance of 25 feet from Table 12-2.
- Make the propagation adjustment according to the following formula (this formula is based on point sources with normal propagation conditions):

$$PPV_{equip} = PPV_{ref} \times \left(\frac{25}{D}\right)^{1.5}$$

where: PPV (equip) is the peak particle velocity in in/sec of the equipment adjusted for distance

PPV (ref) is the reference vibration level in in/sec at 25 feet from Table 12-2

D is the distance from the equipment to the receiver.

- Apply the vibration damage threshold criterion of 0.20 in/sec (approximately 100 VdB) for fragile buildings, or 0.12 in/sec (approximately 95 VdB) for extremely fragile historic buildings. [12]

- If desired for considerations of annoyance or interference with vibration-sensitive activities, estimate the vibration level L_v at any distance D from the following equation and apply the vibration impact criteria in Chapter 8 for vibration-sensitive sites:

$$L_v(D) = L_v(25 \text{ ft}) - 20\log\left(\frac{D}{25}\right)$$

12.2.3 Construction Vibration Mitigation

After using the above approach to locate potential impacts (or damage) from construction vibrations, the next step is to identify control measures. Similar to the approach for construction noise, mitigation of construction vibration requires consideration of equipment location and processes, as follows:

1. *Design considerations and project layout:*
   - Route heavily loaded trucks away from residential streets, if possible. Select streets with fewest homes, if no alternatives are available.
   - Operate earthmoving equipment on the construction lot as far away from vibration-sensitive sites as possible.
2. *Sequence of operations:*
   - Phase demolition, earthmoving and ground-impacting operations so as not to occur in the same time period. Unlike noise, the total vibration level produced could be significantly less when each vibration source operates separately.
   - Avoid nighttime activities. People are more aware of vibration in their homes during the nighttime hours.
3. *Alternative construction methods:*
   - Avoid impact pile driving where possible in vibration-sensitive areas. Drilled piles or the use of a sonic or vibratory pile driver causes lower vibration levels where the geological conditions permit their use (however, see cautionary note below).
   - Select demolition methods not involving impact, where possible. For example, sawing bridge decks into sections that can be loaded onto trucks results in lower vibration levels than impact demolition by pavement breakers, and milling generates lower vibration levels than excavation using clam shell or chisel drops.
   - Avoid vibratory rollers and packers near sensitive areas.

Pile driving is potentially the greatest source of vibration associated with equipment used during construction of a project. The source levels in Table 12-2 indicate that sonic pile drivers may provide substantial reduction of vibration levels. However, there are some additional vibration effects of sonic pile drivers that may limit their use in sensitive locations. A sonic pile driver operates by continuously shaking the pile at a fixed frequency, literally vibrating it into the ground. Vibratory pile drivers operate on the same principle, but at a different frequency. However, continuous operation at a fixed frequency may be more noticeable to nearby residents, even at lower vibration levels. Furthermore, the steady-state excitation of the ground may increase resonance response of building components. Resonant response may be unacceptable in cases of fragile historical buildings or vibration-sensitive manufacturing processes. Impact pile drivers, on the other hand, produce a high vibration level for a short time (0.2 seconds) with sufficient time between impacts to allow any resonant response to decay.

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