GENERIC THIRD-OCTAVE BAND VIBRATION SPECTRA FOR CONSTRUCTION EQUIPMENT

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1 Introduction

A review of the literature on assessments of the impact of construction vibration on sensitive buildings and activities suggests that there is a reliance on total vibration levels without consideration of the spectra of different equipment. The author has reviewed several sources of information, including measurement reports, textbooks [1,2], conference publications [3 - 5], and regulatory guideline documents [6] to arrive at generic spectra for nineteen different types of construction equipment.

The methodology relied upon the available information about total vibration levels and assumptions regarding different frequency regimes. At low frequency, a constant displacement was assumed that transitions at mid-frequencies to constant velocity, followed at high frequencies by constant acceleration. The resulting spectra from 1 Hz to 250 Hz correspond to the information available from other sources in a generic sense. The application of these construction-equipment spectra requires further information about the propagation losses of vibration from a construction site to a sensitive building or activity. Methods for documenting propagation losses are also addressed [7, 8].

2 Development of Vibration Velocity Spectra

The procedure for creating generic spectra relies, first and foremost, on the available peak particle velocity (PPV) of representative construction equipment, typically expressed as a total amplitude in the time domain. This was done through the review of literature described above. With reference to available spectral measurement data, an assessment was made of the number of 1/3-octave bands that were effectively plateauing in the mid-frequency range where constant vibration velocity was assumed. The percentage of energy in these plateaud 1/3-octave bands was determined and then the amplitudes/levels in the lower and higher frequency ranges were determined using adjustments for constant acceleration and constant displacement, respectively. The rationale for assuming three regimes is based on inspection of published measurement data that was reviewed as part of the analysis done to support development of this publication. The following equation was used to determine the 1/3-octave band levels in the constant velocity region of the frequency domain using the information shown in Table 1:

$$\sqrt{\text{Highest FrequencyDomain PPV}^{2} * \frac{\%\ \text{Energy}}{\text{Number 1/3 Octaves}}} \quad (1)$$

Table 1: Summary of Assumed Construction Equipment Spectral Characteristics.

Equipment Class	Highest 1/3-Octave Band, Hz	% Energy	Number 1/3-Octaves	Highest Frequency Domain PPV @ 25 ft, in/sec
Excavator (Auger Drill)	10	80	5	0.008
Compactor, Vibratory	31.5	80	1	0.00577
Concrete Mixer	40	80	5	0.00165
Truck, Concrete Pump	16	80	5	0.00656
Truck, Concrete	16	80	5	0.00656
Concrete Vibrator	20	80	5	0.00060
Crane (Material Handling)	16	80	5	0.00656
Drill, Rock + Compressor	31.5	80	3	0.00268
Truck, Dump	16	80	5	0.00656
Excavator / Loader / Backhoe (Bucket)	12.5	80	5	0.00769
Forklift	25	100	5	0.00008
Grader	8	80	7	0.00099
Hammer, Riveting + Compressor	20	80	5	0.00151
Jackhammer + Compressor	20	80	4	0.00241
Pneumatic Tools + Compressor	20	80	5	0.00030
Saw, Concrete + Generator	63	80	3	0.00027
Truck, Flat-Bed	16	80	5	0.00656
Truck, Medium	20	80	5	0.00328
Welder	80	100	9	0.00001

The results are shown in Figure 1 from 1 Hz to 250 Hz for each of the nineteen equipment classes. As can be seen, a vibratory compactor is expected to have regimes of constant acceleration and constant displacement but no central region in the frequency domain where constant velocity is evident.

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A jackhammer, being an impulsive vibration source, is expected to have more of a broadband characteristic, although the results shown also assume that there are harmonics of the fundamental impact frequency that come into play. Based on prior measurement experience, harmonics may also be evident for a vibratory compactor.

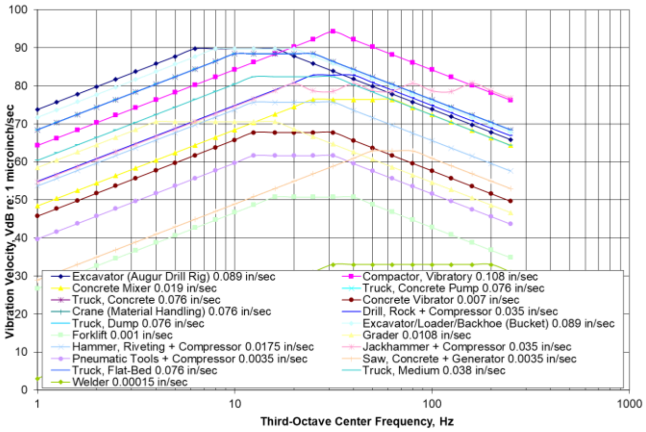

Figure 1: Generic Construction Equipment Vibration Velocity Level Spectra @ 25 ft.

3 Attenuation Law

Reference [8] provides a good framework for addressing the propagation of vibration from construction equipment through the ground. The attenuation law is given by :

$$V/Vi = D^*(Ri/R)^n \tag{2}$$

V = Vibration amplitude at distance R.
Vi = Vibration amplitude at reference distance Ri.
n = Exponent of the attenuation law.
D = Factor taking account of the transmitting medium.

The appropriate exponent n for amplitude reduction depends on the following factors (see Table 2):

- The geometry of the vibration source (e.g., point, line).
- The predominant type of wave (e.g., Rayleigh, body).
- The type of excitation (e.g., steady state, impulsive).

Table 2: Factor n for Construction Equipment Point Sources

Excitation	Rayleigh	Body
Steady State	0.5	1.0
Impulsive	1.0	1.5

To apply the values in Table 2 it is necessary to assume that the vibration energy is apportioned between Rayleigh (i.e., surface waves) and/or body waves that are dominant at depth below a ground surface [9].

The material term D is given by D = exp([-α(R-Ri)]) with the attenuation coefficient α = 2 π ς / λ where ς is the damping ratio of the transmitting medium and λ is the wavelength. For loose soils, ς can be assumed to be 0.01.

Reference [7] provides an alternative formulation that relies on time-domain exponential absorption coefficients to determine the rate of propagation loss through a variety of soil types. These are catalogued for illustration. The attenuation law of reference [8] can potentially be applied if the damping ratio of soil is known or can otherwise be determined through measurement. Ideally, frequency dependent.

4 Conclusion

The information provided above provides a framework for the generic estimation of construction equipment vibration levels at receptors of concern. The results can be improved if measurements are conducted of actual construction activity to determine vibration levels at a typical reference distance and/or the propagation loss from a construction site to a sensitive receptor property.

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References

[1] F. E. Richart, Jr. J. R. Hall, and R. D. Woods. Vibrations of Soils and Foundations. Prentice Hall: 1970.

[2] Charles H. Dowding. Construction Vibrations, 2nd Edition. Prentice-Hall: 2000.

[3] Todd Busch. An Analysis of Two Cities and a State where Construction Noise and Vibration are Uniquely Regulated. Canadian Acoustics 114 Vol.45 No.3: 2017.

[4] Michael J. Wesolowsky, Melissa W.Y. Wong, Todd A. Busch, and John C. Swallow. The Day the Earth Shook: Controlling Construction-Induced Vibrations in Sensitive Occupancies. Dynamics of Civil Structures, Volume 2, pp. 321-327: 2017.

[5] Hal Amick and Michael Gendreau. Construction Vibrations and Their Impact on Vibration-Sensitive Facilities. American Society of Civil Engineers Construction Congress 6, Orlando, Florida: 2000.

[6] Federal Transit Administration. Report No. 0123, Transit Noise and Vibration Assessment Manual. U.S. Department of Transportation, Washington, D.C.: 2018.

[7] Hal Amick. A Frequency-Dependent Soil Propagation Model. SPIE Conference on Current Developments in Vibration Control for Optomechanical Systems. Denver, Colorado: 1999.

[8] Hugo Bachman, Vibration Problems in Structures: Practical Guidelines 2nd Edition,Birkauser Verlag, Boston: 1996.

[9] J.F. Wiss, Construction Vibrations: State of the Art, Journal of the Geotechnical Division, ASCE, v.107, no. GT2, Proc. Paper. 16030, February 1981.