

## 8. VIBRATION IMPACT CRITERIA

Because of the relatively rare occurrence of annoyance due to ground-borne vibration and noise, there has been only limited sponsored research of human response to building vibration and structure-borne noise. However, with the construction of new rail rapid transit systems in the past 30 years, considerable experience has been gained as to how people react to various levels of building vibration. This experience, combined with the available national and international standards,<sup>(1,2,3)</sup> represents a good foundation for predicting annoyance from ground-borne noise and vibration in residential areas as well as interference with vibration-sensitive activities.

The criteria for environmental impact from ground-borne vibration and noise are based on the maximum root-mean-square (rms) vibration levels for repeated events of the same source. The criteria presented in Table 8-1 account for variation in project types as well as the frequency of events, which differ widely among transit projects. Most experience is with the community response to ground-borne vibration from rail rapid transit systems with typical headways in the range of 3 to 10 minutes and each vibration event lasting less than 10 seconds. It is intuitive that when there will be many fewer events each day, as is typical for commuter rail projects, it should take higher vibration levels to evoke the same community response. This is accounted for in the criteria by distinguishing between projects with varying numbers of events, where *Frequent Events* are defined as more than 70 events per day, *Occasional Events* range between 30 and 70 events per day, and *Infrequent Events* are fewer than 30 events per day. Most commuter rail branch lines will fall into the infrequent events category, although the trunk lines of some commuter rail lines serving major cities are in the occasional events category.

The criteria are primarily based on experience with passenger train operations with only limited experience from freight train operations. The difference is that passenger train operations, whether rapid transit, commuter rail, or intercity passenger railroad, create vibration events that last less than about 10 seconds. A typical line-haul freight train is about 5000 feet long. At a speed of 30 mph, it will take a 5000-foot freight train approximately two minutes to pass. Even though the criteria are primarily based on experience with shorter vibration events and this manual is oriented to transit projects, there will be

situations where potential impacts from freight train ground-borne vibration will need to be evaluated. The prime example is when freight train tracks must be relocated to provide space for a transit project within a railroad right-of-way. Some guidelines for applying these criteria to freight train operations are given later in this chapter.

## **8.1 VIBRATION IMPACT CRITERIA FOR GENERAL ASSESSMENT**

### **8.1.1 Sensitive-Use Categories**

The criteria for acceptable ground-borne vibration are expressed in terms of rms velocity levels in decibels and the criteria for acceptable ground-borne noise are expressed in terms of A-weighted sound levels. The limits are specified for the three land-use categories defined below:

- **Vibration Category 1 - High Sensitivity:** Included in Category 1 are buildings where vibration would interfere with operations within the building, including levels that may be well below those associated with human annoyance. Concert halls and other special-use facilities are covered separately in Table 8-2. Typical land uses covered by Category 1 are: vibration-sensitive research and manufacturing, hospitals with vibration-sensitive equipment, and university research operations. The degree of sensitivity to vibration will depend on the specific equipment that will be affected by the vibration. Equipment such as electron microscopes and high resolution lithographic equipment can be very sensitive to vibration, and even normal optical microscopes will sometimes be difficult to use when vibration is well below the human annoyance level. Manufacturing of computer chips is an example of a vibration-sensitive process.

The vibration limits for Vibration Category 1 are based on acceptable vibration for moderately vibration-sensitive equipment such as optical microscopes and electron microscopes with vibration isolation systems. Defining limits for equipment that is even more sensitive requires a detailed review of the specific equipment involved. This type of review is usually performed during the Detailed Analysis associated with the final design phase and not as part of the environmental impact assessment. Mitigation of transit vibration that affects sensitive equipment typically involves modification of the equipment mounting system or relocation of the equipment rather than applying vibration control measures to the transit project.

Note that this category does not include most computer installations or telephone switching equipment. Although the owners of this type of equipment often are very concerned about the potential of ground-borne vibration interrupting smooth operation of their equipment, it is rare for computer or other electronic equipment to be particularly sensitive to vibration. Most such equipment is designed to operate in typical building environments where the equipment may experience occasional shock from bumping and continuous background vibration caused by other equipment.

- **Vibration Category 2 - Residential:** This category covers all residential land uses and any buildings where people sleep, such as hotels and hospitals. No differentiation is made between different types of residential areas. This is primarily because ground-borne vibration and noise are experienced indoors and building occupants have practically no means to reduce their exposure. Even in a noisy

urban area, the bedrooms often will be quiet in buildings that have effective noise insulation and tightly closed windows. Moreover, street traffic often abates at night when transit continues to operate. Hence, an occupant of a bedroom in a noisy urban area is likely to be just as exposed to ground-borne noise and vibration as someone in a quiet suburban area. The criteria apply to the transit-generated ground-borne vibration and noise whether the source is subway or surface running trains.

- **Vibration Category 3 - Institutional:** Vibration Category 3 includes schools, churches, other institutions, and quiet offices that do not have vibration-sensitive equipment, but still have the potential for activity interference. Although it is generally appropriate to include office buildings in this category, it is not appropriate to include all buildings that have any office space. For example, most industrial buildings have office space, but it is not intended that buildings primarily for industrial use be included in this category.

**Table 8-1. Ground-Borne Vibration (GBV) and Ground-Borne Noise (GBN) Impact Criteria for General Assessment**

Land Use Category	GBV Impact Levels (VdB re 1 micro-inch /sec)			GBN Impact Levels (dB re 20 micro Pascals)		
	Frequent Events <sup>1</sup>	Occasional Events <sup>2</sup>	Infrequent Events <sup>3</sup>	Frequent Events <sup>1</sup>	Occasional Events <sup>2</sup>	Infrequent Events <sup>3</sup>
<b>Category 1:</b> Buildings where vibration would interfere with interior operations.	65 VdB <sup>4</sup>	65 VdB <sup>4</sup>	65 VdB <sup>4</sup>	N/A <sup>4</sup>	N/A <sup>4</sup>	N/A <sup>4</sup>
<b>Category 2:</b> Residences and buildings where people normally sleep.	72 VdB	75 VdB	80 VdB	35 dBA	38 dBA	43 dBA
<b>Category 3:</b> Institutional land uses with primarily daytime use.	75 VdB	78 VdB	83 VdB	40 dBA	43 dBA	48 dBA

**Notes:**

1. "Frequent Events" is defined as more than 70 vibration events of the same source per day. Most rapid transit projects fall into this category.
2. "Occasional Events" is defined as between 30 and 70 vibration events of the same source per day. Most commuter trunk lines have this many operations.
3. "Infrequent Events" is defined as fewer than 30 vibration events of the same kind per day. This category includes most commuter rail branch lines.
4. This criterion limit is based on levels that are acceptable for most moderately sensitive equipment such as optical microscopes. Vibration-sensitive manufacturing or research will require detailed evaluation to define the acceptable vibration levels. Ensuring lower vibration levels in a building often requires special design of the HVAC systems and stiffened floors.
5. Vibration-sensitive equipment is generally not sensitive to ground-borne noise.

There are some buildings, such as concert halls, TV and recording studios, and theaters, that can be very sensitive to vibration and noise but do not fit into any of the three categories. Because of the sensitivity of these buildings, they usually warrant special attention during the environmental assessment of a transit project. Table 8-2 gives criteria for acceptable levels of ground-borne vibration and noise for various types of special buildings.

Type of Building or Room	Ground-Borne Vibration Impact Levels (VdB re 1 micro-inch/sec)		Ground-Borne Noise Impact Levels (dB re 20 micro-Pascals)	
	Frequent <sup>1</sup> Events	Occasional or Infrequent <sup>2</sup> Events	Frequent <sup>1</sup> Events	Occasional or Infrequent <sup>2</sup> Events
Concert Halls	65 VdB	65 VdB	25 dBA	25 dBA
TV Studios	65 VdB	65 VdB	25 dBA	25 dBA
Recording Studios	65 VdB	65 VdB	25 dBA	25 dBA
Auditoriums	72 VdB	80 VdB	30 dBA	38 dBA
Theaters	72 VdB	80 VdB	35 dBA	43 dBA

Notes:  
 1. "Frequent Events" is defined as more than 70 vibration events per day. Most rapid transit projects fall into this category.  
 2. "Occasional or Infrequent Events" is defined as fewer than 70 vibration events per day. This category includes most commuter rail systems.  
 3. If the building will rarely be occupied when the trains are operating, there is no need to consider impact. As an example, consider locating a commuter rail line next to a concert hall. If no commuter trains will operate after 7 pm, it should be rare that the trains interfere with the use of the hall.

The criteria in Tables 8-1 and 8-2 are related to ground-borne vibration causing human annoyance or interfering with use of vibration-sensitive equipment. It is extremely rare for vibration from train operations to cause any sort of building damage, even minor cosmetic damage. However, there is sometimes concern about damage to fragile historic buildings located near the right-of-way. Even in these cases, damage is unlikely except when the track will be very close to the structure. Damage thresholds that apply to these structures are discussed in Section 12.2.2.

**8.1.2 Existing Vibration Conditions**

One factor not incorporated in the criteria is how to account for existing vibration. In most cases, the existing environment does not include a significant number of perceptible ground-borne vibration or noise events. The most common example of needing to account for the pre-existing vibration is when the project will be located in an existing rail corridor. When the project will cause vibration more than 5 VdB greater than the existing source, the existing source can be ignored and the standard vibration criteria applied to the project. Following are methods of handling representative scenarios:

1. *Infrequently-used rail corridor (fewer than 5 trains per day):* Use the general vibration criteria, Tables 8-1 and 8-2.

2. *Moderately-used rail corridor (5 to 12 trains per day):* If the existing train vibration exceeds the impact criteria given in Tables 8-1 and 8-2, there will be no impact from the project vibration if the levels estimated using the procedures outlined in either Chapter 10 or 11 are at least 5VdB less than the existing train vibration. Otherwise, vibration criteria in Tables 8-1 and 8-2 apply to the project. The existing train vibration can be either measured or estimated using the General Assessment procedures in Chapter 10. It is usually preferable to measure vibration from existing train traffic.
3. *Heavily-used rail corridor (more than 12 trains per day):* If the existing train vibration exceeds the impact criteria given in Tables 8-1 and 8-2, the project will cause additional impact if the project significantly increases the number of vibration events. Approximately doubling the number of events is required for a significant increase.

If there is not a significant increase in vibration events, there will be additional impact only if the project vibration, estimated using the procedures of Chapters 10 or 11, will be 3 VdB or more higher than the existing vibration. An example of a case with no additional impact would be an automated people mover system planned for a corridor with an existing rapid transit service with 220 trains per day. On the other hand, there could be impact if it is a new commuter rail line planned to share a corridor with the rapid transit system. In this latter case, the project vibrations are likely to be higher than the existing vibrations by 3 VdB or more.

4. *Moving existing tracks:* Another scenario where existing vibration can be significant is when a new transit project will use an existing railroad right-of-way and result in shifting the location of existing railroad tracks. The track relocation and reconstruction can result in lower vibration levels, in which case this aspect of the project represents a benefit, not an adverse impact. If the track relocation will cause higher vibration levels at sensitive receptors, then the projected vibration levels must be compared to the appropriate impact criterion to determine if there will be new impacts. If impact is judged to have existed prior to moving the tracks, new impact will be assessed only if the relocation results in more than a 3 VdB increase in vibration level.

### **8.1.3 Application to Freight Trains**

The impact thresholds given in Tables 8-1 and 8-2 are based on experience with vibration from rail transit systems. They have been used to assess vibration from freight trains since no specific impact criteria exist for freight railroads. However, the significantly greater length, weight and axle loads of freight trains make it problematic to use these impact criteria for freight rail. Nevertheless, in shared right-of-way situations where the proposed transit alignment causes the freight tracks to be moved closer to sensitive sites, these impact criteria will have to be used. In assessing the freight train vibration, a dual approach is recommended with separate consideration of the locomotive and rail car vibration. Because the locomotive vibration only lasts for a very short time, the few-event criterion is appropriate for fewer than 30 events per day. However, for a typical line-haul freight train where the rail car vibration lasts for several minutes, the many-event limits should be applied to the rail car vibration. Some judgment must be exercised to make sure that the approach is reasonable. For example, some spur rail lines carry very

little rail traffic (sometimes only one train per week) or have short trains, in which case the criteria may be disregarded altogether.

Finally, it should be pointed out that the vibration control measures developed for rail transit systems are not effective for freight trains. Consequently, any decision to relocate freight tracks closer to sensitive sites should be made with the understanding that the increased vibration impact due to freight rail will be very difficult, if not impossible, to mitigate.

## **8.2 VIBRATION IMPACT CRITERIA FOR DETAILED ANALYSIS**

### **8.2.1 Ground-Borne Vibration**

Specification of mitigation measures requires more detailed information and more refined impact criteria than what were used in the General Assessment. A frequency distribution, or spectrum, of the vibration energy determines whether the vibrations are likely to generate a significant response in a receiving building or structure. The Detailed Analysis method in this manual provides an estimate of building response in terms of a one-third octave band frequency spectrum. This section provides criteria for assessing the potential for interference or annoyance from building response and for determining the performance of vibration reduction methods.

International standards have been developed for the effects of vibration on people in buildings with ratings related to annoyance and interference with activities based on frequency distribution of acceptable vibrations.<sup>(2)</sup> These criteria have been supplemented by industry standards for vibration-sensitive equipment.<sup>(3)</sup> Both sets of criteria are expressed in terms of one-third octave band velocity spectra, with transient events like train passbys described in terms of the maximum rms vibration velocity level with a one-second averaging time. The measurement point is specified as the floor of the receiving building at the location of the prescribed activity.

The vibration impact criteria are shown in Figure 8-1 where the international standard curves and the industry standards are plotted on the same figure. Interpretations of the various levels are presented in Table 8-3. Detailed Analysis results in one-third octave band spectra levels that are plotted over the curves shown in Figure 8-1. Band levels that exceed a particular criterion curve indicate the need for mitigation and the frequency range within which the treatment needs to be effective.

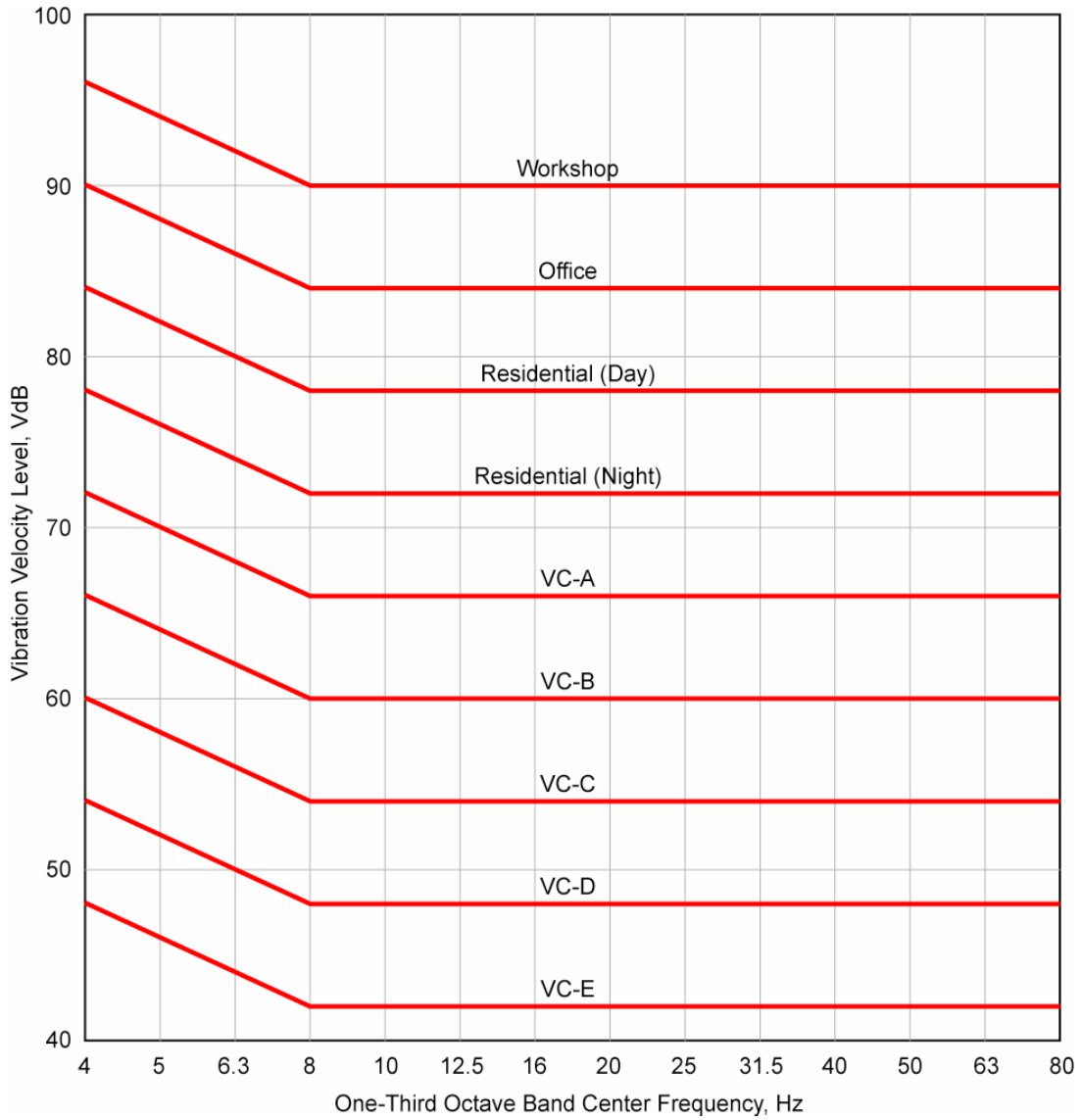


Figure 8-1. Criteria for Detailed Vibration Analysis

**Table 8-3. Interpretation of Vibration Criteria for Detailed Analysis**

Criterion Curve <sup>1</sup> (See Figure 8-1)	Max L <sub>v</sub> (VdB) <sup>2</sup>	Description of Use
Workshop	90	Distinctly feelable vibration. Appropriate to workshops and non-sensitive areas.
Office	84	Feelable vibration. Appropriate to offices and non-sensitive areas.
Residential Day	78	Barely feelable vibration. Adequate for computer equipment and low-power optical microscopes (up to 20X).
Residential Night, Operating Rooms	72	Vibration not feelable, but ground-borne noise may be audible inside quiet rooms. Suitable for medium-power optical microscopes (100X) and other equipment of low sensitivity.
VC-A	66	Adequate for medium- to high-power optical microscopes (400X), microbalances, optical balances, and similar specialized equipment.
VC-B	60	Adequate for high-power optical microscopes (1000X), inspection and lithography equipment to 3 micron line widths.
VC-C	54	Appropriate for most lithography and inspection equipment to 1 micron detail size.
VC-D	48	Suitable in most instances for the most demanding equipment, including electron microscopes operating to the limits of their capability.
VC-E	42	The most demanding criterion for extremely vibration-sensitive equipment.

<sup>1</sup>Descriptors on curves are those provided by References 2 and 3.

<sup>2</sup>As measured in 1/3-octave bands of frequency over the frequency range 8 to 80 Hz.

These criteria use a frequency spectrum because vibration-related problems generally occur due to resonances of the structural components of a building or vibration-sensitive equipment. Resonant response is frequency-dependent. A Detailed Analysis can provide an assessment that identifies potential problems resulting from resonances.

The detailed vibration criteria are based on generic cases when people are standing or equipment is mounted on the floor in a conventional manner. Consequently, the criteria are less stringent at very low frequencies below 8 Hz. Where special vibration isolation has been provided in the form of pneumatic isolators, the resonant frequency of the isolation system is very low. Consequently, in this special case, the curves may be extended flat at lower frequencies.

### 8.2.2 Ground-Borne Noise

Ground-borne noise impacts are assessed based on criteria for human annoyance and activity interference. The results of the Detailed Analysis provide vibration spectra inside a building. These vibration spectra can be converted to sound pressure level spectra in the occupied spaces using the method described in Section 11.2.2. For residential buildings, the criteria for acceptability are given in terms of the A-weighted sound pressure level in Table 8-1. For special buildings listed in Table 8-2, a single-valued level may not be sufficient to assess activity interference at the Detailed Analysis stage. Each special building may have a unique specification for acceptable noise levels. For example, a recording studio may have stringent requirements for allowable noise in each frequency band. Therefore, the ground-borne noise criteria for each sensitive building in this category will have to be determined on a case-by-case basis.

## REFERENCES

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1. Acoustical Society of America, "American National Standard: Guide to Evaluation of Human Exposure to Vibration in Buildings," ANSI S3.29-1983 (ASA 48-1983).
2. International Organization for Standardization, "Evaluation of Human Exposure to Whole-Body Vibration, Part 2: Continuous and Shock-Induced Vibrations in Buildings (1-80Hz)," ISO-2361-2, 1989.
3. Institute of Environmental Sciences and Technology, "Considerations in Clean Room Design," RR-CC012.1, 1993.

