

Protecting vibration environments with zoning and land-use ordinances

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1. INTRODUCTION

Historically, the primary purposes of municipal land use zoning ordinances are to protect and promote a desired quality of life and to ensure that incompatible land uses do not occur. These ordinances often arise from concerns expressed by individuals and businesses in a community. Zoning considers aspects of community planning such as compatibility of adjacent land uses, aesthetics, housing needs, protection and development of natural resources, population density, and environmental quality. Typical environmental quality considerations include water, air, solid waste, and noise. Seldom, if ever, are vibrations considered; when they are, it is often in the form of a vague nuisance ordinance applying only to the effects of vibrations on people. Rarely does the vibration ordinance quantify the acceptable limit or describe how the vibrations should be measured. Unfortunately, the needs of the high-technology community, with very stringent vibration requirements, are generally not represented in these ordinances.

A good planning tool is needed for the siting and planning of research and industrial areas containing sensitive high-tech facilities, such as those used in microelectronics manufacturing. These facilities are generally far more sensitive to vibrations than are people. Yet, despite their sensitivity, they are offered no encroachment protection from vibration by zoning ordinances. In most areas, a paper mill might be zoned the same as a wafer fab, yet pose a severe problem for the fab's vibration environment.

The paper reviews the vibration issues which should be considered in siting high-technology facilities and proposes some guidelines for ordinances which address these issues.

2. PURPOSE OF ZONING ORDINANCES

Zoning ordinances protect residential communities from the noise, odor, and traffic congestion that may accompany industrial and commercial developments. In doing so, a higher quality of life is maintained. These ordinances also protect commercial and industrial properties from the more stringent requirements imposed in residential communities. A well-planned community containing areas of commercial, industrial, and residential land uses will protect land values and can provide for orderly growth and development in accordance with the goals of the community.

Almost all municipalities in the State of California have developed noise ordinances and are mandated by state law to have a noise element as part of their general plan for future development. Many communities have established noise ordinances that set property line noise level limits; provide definitions, measurement descriptors, and measurement criteria; or impose time or level limits on various specific activities and describe enforcement procedures. Few regulations include vibration in a meaningful or enforceable manner. We are not aware of any ordinance that would protect the interests of vibration-sensitive industries.

Few existing vibration ordinances offer the measurement and processing guidance found in a noise ordinance. For example, the noise control ordinance of the County of Los Angeles (Ord. No. 11,743) states that acceptable vibration is "the minimum ground or structure-borne vibrational motion necessary to cause a normal person to be aware of the vibration by such direct means as, but not limited to, sensation by touch or visual observation of moving objects. The perception threshold shall be presumed to be a motion velocity of 0.01 in./sec over the

range of 1 to 100 Hz." The ordinance only addresses human annoyance. Even at that, the ordinance does not indicate how data are filtered, processed, and compared to the criterion in terms of peak particle velocity, maximum particle velocity in one direction, rms velocity, one-third octave bands, or constant bandwidth. There is no provision for use of energy equivalent or centile values (e.g. L_{eq} , L_{10} , L_1 , or L_{max}). The Los Angeles ordinance specifies measurements at the property line, but allows for subjective "awareness" of vibration such as observed motion of objects and are intended to provide adequate human comfort within habitable areas in buildings. In its noise requirements, this same ordinance provides for four noise zones of differing stringency dictated by land use of a receptor site (Noise Sensitive Area, Residential Property, Commercial Property, Industrial Property) and is quite specific regarding the measurement and analysis of noise.

3. NEED FOR VIBRATION ORDINANCES

Vibrations should be included in municipal ordinances and land use considerations for many of the same reasons that noise is considered. Like noise, vibration can interfere with comfort, working efficiency, and the health and safety of people. The International Organization for Standardization has addressed many of the vibration concerns as they relate to people--ISO 2631, *Guide for the Evaluation of Human Exposure to Whole-Body Vibration*. Criteria have been set which consider the preservation of comfort. This set of criteria should be used in developing municipal ordinances which can be used by land use planners to protect the public's environment. Likewise, criteria for special vibration-sensitive land uses that would protect high-tech industries from vibration should be incorporated into the ordinance.

Vibration can also interfere with industrial and scientific processes that are highly sensitive to vibrations--often many times more sensitive to vibration than are people. These processes include those of the biomedical field where dimensions the size of a single cell are important and those of the microelectronics field (integrated circuits) where line widths less than 1 micrometer must be produced. However, city planners normally are not aware of the sensitivity of high-tech facilities to vibration. Consequently, land-use planning and zoning do not take into account the special requirements of these scientific and high-tech facilities, which are generally not compatible with multi-lane freeways, rail corridors, or industries with large mechanical equipment. It is important to protect existing vibration-sensitive facilities, provide guidance for industrial expansion, and provide protection for future facilities.

A significant amount of design effort goes into minimizing vibrations generated inside a high-tech building. Unfortunately, without properly-formulated vibration ordinances there is little one can do to protect against vibrations generated off-site, perhaps in a neighboring facility. Prior to design and construction, building owners may commission a site vibration survey to qualify a potential site; excessive vibrations at the site may lead to its rejection. A recent client's preferred site was rejected because of vibrations from a paper mill on neighboring property. The owner selected another site with an office building on one side and open area zoned industrial on the other. Having found this site acceptable, the owner would prefer that it stay that way, but there are no regulatory means to deal with someone wishing to locate vibration-generating industry next door. A carefully designed low-vibration environment can be rendered ineffective if a "heavy" industrial facility is later built next door.

In order to prevent such a disaster, the high-tech industry should work with city planners to develop a planning tool for siting and protecting vibration-sensitive research and industrial areas. This planning tool should be fairly comprehensive and include the needs of both residential areas and the high-tech industry. The planning tool can take the form of a zoning ordinance, which city planners use during the permitting and reviewing process to consider possible impacts of vibration on the high-tech industry.

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The zoning ordinance should consider proximity to heavy manufacturing or heavy transportation (buses, trucks, and trains) and provide a zoning category for only high-tech, vibration-sensitive industry with a *buffer* of some sort between sensitive sites and nearby sources of vibrations. We encourage owners and operators of high-tech facilities to work with city planners to sensitize them to the concerns of the industry and to assist in the development of guidelines that will protect their interest.

4. RECOMMENDATIONS

New ordinances are recommended, which would (1) define acceptable property-line vibration levels based upon land use, recognizing that high-tech facilities require *special* ground vibration limits, (2) define field measurement procedures, (3) define the requirements for processing and presenting the vibration measurements such as rms velocity in one-third octave bands using energy average (L_{eq}) and L_{max} levels, and (4) provide means of enforcement.

4.1 Recommended vibration levels for human exposure.

The draft addendum to ISO Standard 2631 recommends satisfactory magnitudes of vibration to preserve the comfort in various human environments. Table 1 summarizes the suggested satisfactory magnitudes of building vibration for various land use types, ISO 2631/DAD 1. These recommended levels apply to values of rms velocity amplitude in one-third octave bands with center frequencies between 2 and 80 Hz measured at the place of occupancy.

There is common acceptance regarding the ISO guidelines, which are recommended as a starting point for evaluating the majority of land use compatibility. These guidelines are based upon human reaction to vibration. However, the effects of vibration on sensitive equipment and processes found in high-tech facilities were beyond the scope of ISO.

Table 1. Summary ISO 2361/DAD 1 Vibration Levels

Land Use	Time	Vibration Limit dB re 1 μ in./sec
Hospital Operating Theater and other critical work areas	Day	72
	Night	72
Residential	Day	78
	Night	75
Office	Day	84
	Night	84
Workshop	Day	90
	Night	90

4.2 Recommended vibration levels for high-tech industries.

Equipment used for high-tech manufacturing, research, and development generally specifies very stringent environmental limitations on such aspects as temperature, humidity, cleanliness, and vibration. In most instances, the required construction methods lead to a building far more expensive than a conventional industrial or office building of the same size.

In our experience with the siting and design of high-tech facilities we have developed the criterion curves A through E shown in Figure 1 which have the same format as ISO and are evaluated in roughly the same manner. Several ISO curves are shown for reference. These curves are to be compared with rms velocity levels in one-third octave bands. If the curves are used to evaluate an outdoor site, the data are gathered over a 20-30 minute period and processed in a manner yielding L_{eq} spectra. The spectra obtained in this manner are expected to lie at least 6 to 10 dB below the criterion for the facility to allow for vibrations that will be contributed by building operation.

4.3 Recommended guidelines for vibration ordinances.

Proper inclusion of the above provisions into land use planning documents and local ordinances by the high-tech industry will be better protected from high levels of vibration. High-tech industries must work with local communities to provide low-vibration areas and ensure that future development, both private and public, is compatible with these vibration-sensitive facilities. It is time that a model vibration ordinance be developed.

Measurement procedures must be clearly stated if reliable and enforceable information is to be collected. The accelerometer must be extremely sensitive in order to measure the extremely small levels of vibration associated with high-tech facilities, in the range 1 to 10 volt per g, and be able to measure over the appropriate frequency range, typically between 2 Hz to 100 Hz.

We recommend the ISO guidelines for analysis using one-third-octave band rms velocity level. Like environmental noise, environmental vibration levels are constantly changing requiring the use of statistical quantities. We recommend the use of L_{eq} for steady-state conditions and L_{max} for single event sources such as rail traffic or cyclic sources such as punch presses. Measurement duration and location guidelines should also be provided in the ordinance.

The criterion should clearly state the amplitude limits, the units of measure, frequency range, frequency bandwidth and measurement "statistic." The criterion should be land-use dependent, and be easily applied to proposed developments seeking permits in designated vibration-sensitive land-use zones.

