TruHorizon
Environmental Solutions

Case Study – *ESTABLISHING CRITERIA FOR UTILIZING MEASURED DATA WHEN FACED WITH NUISANCE BASED ORDINANCES*

When faced with arbitrary rules from a governing body, the question arises, how do you establish your position fairly? This case study was created based on a situation TruHorizon encountered, where the current ordinances were vague, unclear, and nuisance based, therefore making the answer of compliance arbitrary. What follows is our approach to such a problem.

Sound and Vibration Overview

Sound

Noise is defined as "any perceived sound that is objectionable to a human being." (Barenek 1). Although responses to specific sounds vary from person to person, there are several common effects noise exposure that may occur. Hearing loss may occur when a person is consistently subjected to noise but is subjective and varies between individuals. Sound is typically characterized by a number of variables; the following are two key variables for this study:

- Frequency – Pitch, measured in Hertz ("Hz")
    - Hertz – number of oscillations per second of a periodic wave sound

- Intensity – Loudness, measured in decibels ("dB")
    - Decibel – logarithmic unit used to express the ratio of two values of physical quantity

An important way of determining a person's subjective reaction to a new noise is by comparing it to the existing or "ambient" environment to which that person has adapted. A noise study requires having a control variable to test new results against to measure the change, and the effects of those changes. In general, the more the level or the tonal (frequency) variations of a noise exceeds the previously existing ambient noise level or tonal quality, the less acceptable the new noise may be, as judged by the exposed individual. **Table 1** show some typical sound levels found in the environment.

Table 1: Typical sound levels measured in the environment

Description of Sound	Sound Level (dBA)	Human Perception of Loudness*
Threshold of Hearing	0	
Rustling Leaves	20	Just Audible
Quiet Whisper (3 feet away)	30	Very Quiet
Quiet Home	40	Quiet *(1/8 as loud)*
Quiet Street	50	*(1/4 as loud)*
Normal Conversation	60	*(1/2 as loud)*
Inside Car	70	Moderately Loud *(Reference Loudness)*
Automobile (25 feet away)	80	
Train Whistle (500 feet away)	90	
Level at which sustained exposure may result in hearing loss	90 – 95	
Diesel Truck (30 feet away)	95	
Pile Driver (50 ft.)	100	Very Loud *(8 times as loud)*
Power Mower (3 feet away)	107	
Amplified Rock and Roll (6 feet away)	110	*(16 times as loud)*
Jet Airplane (100 feet away)	120	Threshold of pain *(32 times as loud)*
Civil defense siren (100 ft.)	130	
Firearm shots near ear	140	Painfully Loud
Even short term exposure can cause permanent damage – Loudest recommended exposure WITH hearing protection	140	

*Relative to a Reference Loudness of 70 Decibels – Various Sources: Baranek, 1998, Barnes et al., USEPA, 1971.

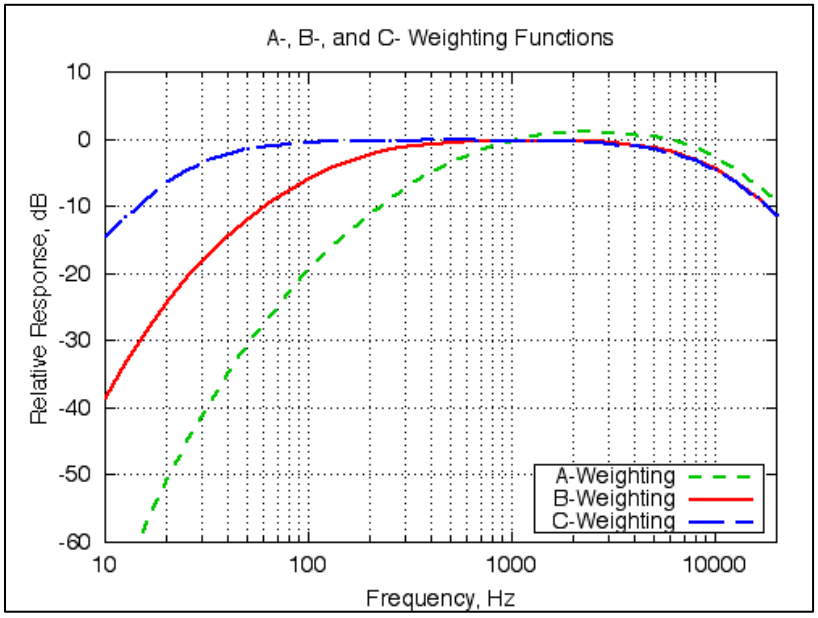
The United States Environmental Protection Agency (USEPA 1974) breaks homes into categories and also examines sounds based on open or closed windows due to the fact that sound levels inside a home are not as loud as those outside. Indoor location levels can be determined by reducing the L_{Aeq} by the warm climate values (the most conservative) in **Table 2.**

Table 2: Sound Level Reduction Due to Home

Climate	Windows Open	Windows Closed
Warm Climate	12 dB	24 dB
Cold Climate	17 dB	27 dB
APPROXIMATE NATIONAL AVERAGE	15 dB	25 dB

Sound pressure level measurements are commonly weighted in relation to their frequency components in order to provide a consistent basis for comparison to other measurements of the same type. **Chart 1** depicts three common weighting curves plotted together for reference.

Chart 1: Decibel Weighting Curves



The A-weighted filter was used during this study which corresponds to the human ear's response at low to medium sound levels. Time weighting defines how the exponential averaging in root-mean-square measurement is done. The A-weighted filter with fast time weighting is common for environmental noise measurement and was used in this study. The C-weighted filter is used for very high sound level measurements and does not filter out low or high frequency sounds. It approximates the human ear at very high sound levels and is typically used for measuring traffic, machinery and other loud sound sources. B-weighting is no longer commonly used and was developed to filter the mid-range frequencies between A and C weighting. Sound is commonly measured in decibels (dB), a measure of sound energy based on a logarithmic scale

The following weighted sound levels were recorded:

- L_{Aeq} – The equivalent continuous sound level over a specified period of time that represents the same energy as the actual time varying sound signal

The 'A' in the above variables denote that the A-weighting has been included.

TruHorizon utilized a Brüel & Kjær Type 2250 sound level meter, 4th generation, hand-held analyzer to measure sound levels at the monitoring location. **Appendix A** lists the manufacturer's specification for this meter. The software modules in the Type 2250 allows for real-time frequency analysis, analysis of time histories for broadband parameters and spectra, and documentation of measurements through recording of measured sound. The 2250 sound level meter continuously

sampled sound levels logging the specified data every minute; therefore, each one hour period provided 60 readings.

Prior to beginning the monitoring, the 2250 meters were calibrated using the Brüel & Kjær Type 4231 Acoustical Calibrator. The calibrator emits a reference sound pressure level of 94 dB. The calibrator was placed on the sound meter to verify the meter was accurately measuring the reference sound level. Full manufacturer calibration documentation is available upon request.

Vibration

Vibration is defined as the oscillatory motion of a mass described in terms of displacement, velocity or acceleration. Displacement is the distance a particle or mass has moved; velocity is the instantaneous speed and direction the particle has moved; and the acceleration is the rate of change of the velocity or speed. Vibration amplitudes are expressed in peak particle velocity (PPV) or the root mean square (RMS) velocity.

For this study, TruHorizon recorded the following vibration levels:

- Transverse PPV – The peak particle velocity measured in the transverse, or x-direction
- Vertical PPV – The peak particle velocity measured in the vertical, or z-direction
- Longitudinal PPV – The peak particle velocity measured in the longitudinal, or y-direction
- Vector Sum PPV – the peak particle velocity measured in the vector sum, or summation of x, y, and z directions

The PPV is typically measured in millimeters or inches per second.

Table 3 shows show some typical vibration source amplitudes from various types of construction equipment, as compiled by the Federal Transit Administration (1995) and Caltrans (2000) for crack-and-seat operations:

Table 3: Vibration Source Amplitudes for Construction Equipment

Equipment	Reference PPV at 25 ft. (in/s)
Vibratory roller	0.210
Large bulldozer	0.089
Caisson drilling	0.089
Loaded trucks	0.076
Jackhammer	0.035
Small bulldozer	0.003
Crack-and-seat operations	2.400

TruHorizon utilized a Brüel & Kjær Type 4450 vibration analyzer to measure vibration levels at the monitoring location. **Appendix A** lists the manufacturer's specifications for this meter. The software modules in the Type 4450 allows for real-time vibration analysis, analysis of time

histories for broadband parameters, and documentation of measurements through recording of measured vibration. The 4450 vibration meter continuously sampled sound levels logging the specified data every minute; therefore, each one hour period provided 60 readings.

Prior to beginning the monitoring, the 4450 meters were calibrated using the Brüel & Kjær reference calibration file. Full manufacturer calibration documentation is available upon request.

After monitoring, the data collected by the 2250 sound level meter and the 4450 vibration level meter was downloaded to a computer using Brüel & Kjær Sentinel Software for Hand-held Analyzers. TruHorizon used the manufacturer's software, coupled with Excel spreadsheets, to summarize the data.

Ordinance Overview

Chapter 11 Section 2 (a) of the City of Woodway Code of Ordinances states "The creation of any loud, disturbing, or unnecessary noise which causes distress, discomfort or injury to persons of ordinary sensibilities in the immediate vicinity thereof…is a public nuisance."

TruHorizon considers sounds above 60 decibels to be a nuisance when no specific limit is defined in the governing ordinance. Sounds in excess of 60 decibels interfere with speech and conversational sound levels. Another commonly used metric to limit commercial and industrial noise is to add a limit to the existing ambient sound level. Other cities have a sound level limit based on the zoning criteria. The nearby City of Waco prohibits sounds in excess of 85 A-weighted decibels (dBA) during daytime hours and 80 dBA during nighttime hours for residential properties and 85 dBA during all hours for all non-residential properties. The City of College Station prohibits sound "during the hours of 7:00 a.m. to 10:00 p.m. that when measured from the property line of a residence located in a residential zoned property that exceeds sixty-three decibels and would disturb or annoy a person of ordinary sensibilities, or…when measured from a contiguous interior wall of a residence that is a multiunit residence located in a residential zoned property that exceeds fifty-five decibels." Nighttime noise is defined from 10:01 p.m. to 6:50 a.m. and may not exceed 56 decibels at the property line or 50 decibels when measured indoors.

The Occupational Safety and Health Administration (OSHA) developed a criteria in 1983 to prevent hearing loss in workers: Continuous A-weighted sound levels are not permitted above 115 dBA regardless of duration, and a permissible exposure level is defined as that noise dose that would result from a continuous eight hour exposure to a sound level of 90 dBA. The limit of 90 dBA over 8 hours is a dose of 100% (Baranek et al. 1992.)

The City of Woodway does not contain any provisions for vibration regulation. For purposes of this study, TruHorizon consulted several studies on the human response to vibration as well as studies on structural damage for comparison and analysis.

Table 4 summarizes the human response to steady state or continuous vibration, from an early study (Reiher, H and F.J. Meister, 1931.) Peak Particle Velocity, or PPV, is a commonly used

measurement for vibration and is defined as the displacement and direction of particles per second due to vibrations.

Table 4: Human Response to Steady State Vibration

PPV (in/s)	Human Response
3.6 (at 2 Hz) – 0.4 (at 20 Hz)	Very disturbing
0.7 (at 2 Hz) – 0.17 (at 20 Hz)	Disturbing
0.10	Strongly perceptible
0.035	Distinctly perceptible
0.012	Slightly perceptible

Table 5 summarizes the human response to transient, or impulsive vibration (Wiss 1974.)

Table 5: Human Response to Transient Vibration

PPV (in/s)	Human Response
2.0	Severe
0.9	Strongly perceptible
0.24	Distinctly perceptible
0.035	Barely perceptible

For purposes of this study, TruHorizon considers vibration from the CrossFit Misfits facility against the human response limits for transient vibration. The primary source of vibration from the facility is dropping weights during a workout, which does not occur during every workout and is transient or impulsive in nature. The limits in **Tables 4** and **5** suggest that thresholds for perception and annoyance are higher for transient vibration than for continuous or steady state vibration.

TruHorizon referenced two studies for the limits on structural damage. The maximum allowable PPV before permanent damage is sustained is recommended by (Dowding 1996) in **Table 6**:

Table 6: Dowding Building Structure Vibration Criteria

Structure and Condition	Limiting or Max PPV (in/s)
Historic and some old buildings	0.5
Residential structures	0.5
New residential structures	1.0
Industrial buildings	2.0
Bridges	2.0

The American Association of State Highway and Transportation Officials (AASHTO 1990) recommends maximum vibration levels for preventing damage to structures from transient construction and maintenance activities in **Table 7**:

Table 7: AASHTO Maximum Vibration Levels for Preventing Damage

Type of Structure	Limiting or Max PPV (in/s)
Historic sites or other critical locations	0.1
Residential buildings, plastered walls	0.2 – 0.3
Residential buildings in good repair with gypsum board walls	0.4 – 0.5
Engineered structures, without plaster	1.0 – 1.5

Sound data for this study is compared against a 60-decibel nuisance level. Vibration data for this study is compared for both the human response to transient vibration and limits for structural damage. The 1974 Wiss study for the human response to transient and impulsive vibration, specifically the "Barely perceptible" PPV limit of 0.035 inches per second is utilized as a conservative approach for human response. The complaint structure is not a registered historic location within the City of Waco or Woodway; and the exact composition and building materials of the structure is unknown. For structural damage, TruHorizon chose the AASHTO max PPV for residential buildings with plastered walls of 0.2 inches per second for comparison. This limit is appropriate for the building type, but still conservative as the building composition is unknown. In Appendix C, the chosen limits are defined as:

- 60 dB Limit – sound clips are generated for all minute A-weighted averages exceeding 60 decibels
- AASHTO Residential Limit
- Wiss "Barely Perceptible" Limit

Through exhaustive research and presentation of rational data, TruHorizon was able to redirect the conversation away from a subjective notion of "nuisance". In the study, TruHorizon was able to utilize the limits established above for sound and vibration. Ultimately, this study ended up in litigation, resulting in a court testimony of the study that the Judge ruled as "conclusive and far more rational than the current stated 'nuisance' ordinance based on the limits established by the consultant (TruHorizon)".

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APPENDIX A

METER MANUFACTURER'S SPECIFICATIONS

PRODUCT DATA

Hand-held Analyzer — Type 2270 with Sound Level Meter Software BZ-7222 Optional Frequency Analysis Software BZ-7223, Logging Software BZ-7224, Enhanced Logging Software BZ-7225 and Sound Recording Option BZ-7226

*The innovative Type 2270 is designed and developed as an advanced solution from model 2250 for measurement, analysis and recording. This fourth generation hand-held analyzer from Brüel & Kjær builds on extensive research among sound and vibration professionals which concluded that the instrument should be **easy** and **safe** to use while at the same time incorporating **clever** features.*

The combination of software modules and innovative hardware makes the instrument into a dedicated solution for performing high-precision measurement tasks, in environmental, occupational and industrial application areas. As a result, you get the functionality you need now, plus the option of opening up for more functionality later as your requirements grow – and your investment is securely protected.

Uses and Features

USES

- Environmental noise assessment and monitoring
- Occupational noise evaluation
- Building acoustic measurements[1)]
- FFT analysis of sound and vibration[1)]
- Noise reduction
- Product quality control
- Class 1 sound measurements to the latest international standards
- Real-time analysis of sound in 1/1- and 1/3-octave bands (option)
- Analysis of time histories for broadband parameters and spectra (Logging) (option)
- Documentation of measurements using photo, text and voice annotations
- Documentation of measurements through recording of measured sound (option)

FEATURES

- Large, dual-channel measurement, high-resolution, touch-sensitive colour screen
- Data storage on CF and SD plug-in memory-cards
- Standard USB and LAN computer interface
- Integrated digital camera for reporting
- Dynamic range in excess of 120 dB
- Broadband and spectral data can be logged to obtain a time history for analysis
- Sound recording of measured signal during all or parts of a measurement (option)
- Timers for automatic start of measurement
- PC software included for setup, archiving, viewing, export and reporting
- CCLD input for vibration or sound measurement
- Trigger input for remote measurement trigger and tacho signal
- Robust and environmentally protected (IP44)

1)For further information, please refer to the relevant product data sheet

Brüel & Kjær

PRODUCT DATA

Vibration Monitoring Terminal Type 3680

Simple and effective vibration monitoring

When you need to reduce the risk of structural damage to nearby buildings, assess human response to vibration or monitor background vibration levels to ensure sensitive equipment operates correctly, you need a robust device on which you can rely.

Brüel & Kjær's Vibration Monitoring Terminal Type 3680 (VMT) achieves it all reliably and with the minimum of effort.

Uses and Features

Uses

Construction and mining
- Fast alerting on triaxial PPV measurements
- Alerts trigger SMS, email or local control of external devices

Road and rail planning
- Continuous monitoring of vibration levels
- Background surveys prior to construction, or routine assessment during operation

Ambient monitoring at hospitals/manufacturing
- Alerts if background levels prevent accurate operation of imaging equipment

Features

Complete solution
- Vibration metrics for a wide range of applications
- Continuous uninterrupted measurement
- Immediate and fast data transfer if thresholds exceeded; generating alerts within a second
- Mains powered or 12-hour operation with integrated backup battery
- Continuous operation on solar power (optional) subject to panel size and local conditions

Easy to operate
- Three status LEDs confirm correct operation or diagnose problems on-site
- Seamless operation with Sentinel: Switch on the unit and it automatically connects and configures itself. The built-in GPS locates the measurement position
- For stand-alone use, a free smartphone app enables set-up, remote display and operation anywhere, as well as data transfer to standard applications like Microsoft® Excel®

Brüel & Kjær