Remote Vibration and Noise Monitoring for Construction

Why monitor?

Construction activities such as pile driving or pavement breaking produce vibrations and noise that can be disruptive to people and damaging to facilities. The effects may extend thousands of feet away from the vibration inducing activity. People have become increasingly intolerant to these effects. Many property owners oppose developments that include pile driving and push for alternatives that may be more expensive, but which may still produce undesirable levels of vibration and noise. Lately, homeowners have been expressing more concerns as they work from home during the COVID-19 pandemic.

Unfortunately, the levels and characteristics of vibration and noise that are perceived by humans are much lower and different from those that can cause damages to buildings. Figure 1 shows a typical plot of the levels of peak particle velocity (PPV) required to produce structural damage at a frequency of 10 Hz. Also shown are the measured peak vibration levels from various construction activities as a function of distance away from the vibration source. The measured data show how PPV decreases with distance from the source. The figure shows that if one is more than 15 feet away from the vibration source for typical pile driving, the vibration level is generally below that which might directly damage a structure. Unless pile driving is occurring within a few feet of a structure it does not commonly cause direct damage to the structure from vibrations. Other undesirable effects, such as indirect damage via soil densification or disruption of sensitive equipment are possible in special cases. Regardless, people located hundreds of feet from the vibration source may be bothered by the repeated vibrations.

Generally, human perception of vibration is frequency dependent; the greater the vibration's frequency, the more perceptible a vibration with the same PPV is to humans. Potential for structural damage is also frequency dependent, but the greater the frequency, the less likely a vibration with the same PPV is to cause damage to a regular building. People begin to perceive vibrations at about 0.01 inch per second (ips), a level of excitation which is orders of magnitude less than what can cause cosmetic damages to buildings. Human perception is also affected by the length of the exposure (Siskind et al., 1980). For example, at 0.5 ips, vibrations change from "distinctly perceptible" to "strongly perceptible" as exposure time extends from 1 to 10 sec.

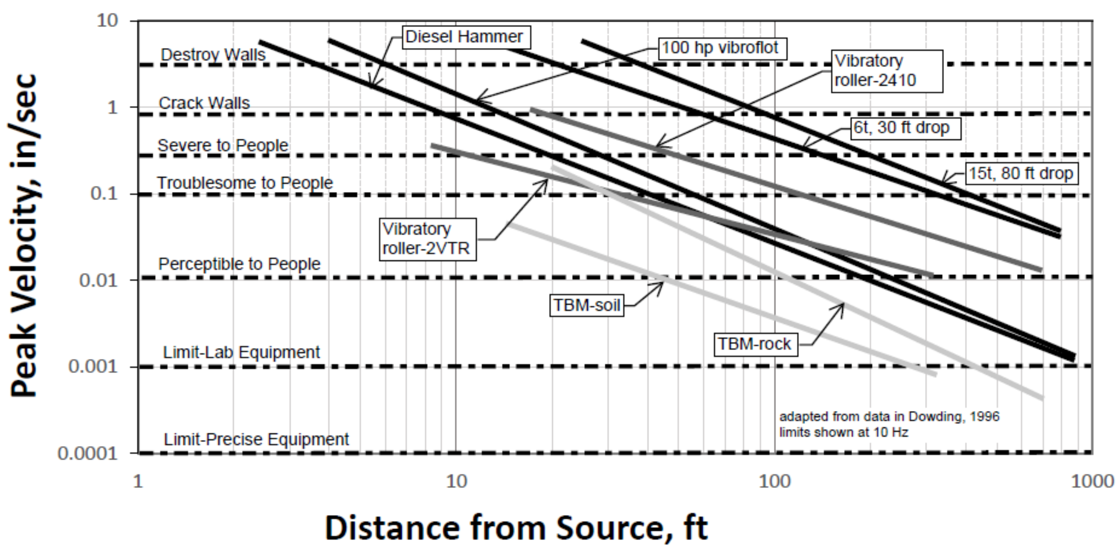


Figure 1 Typical ranges of measured PPV vs. distance for various construction equipment

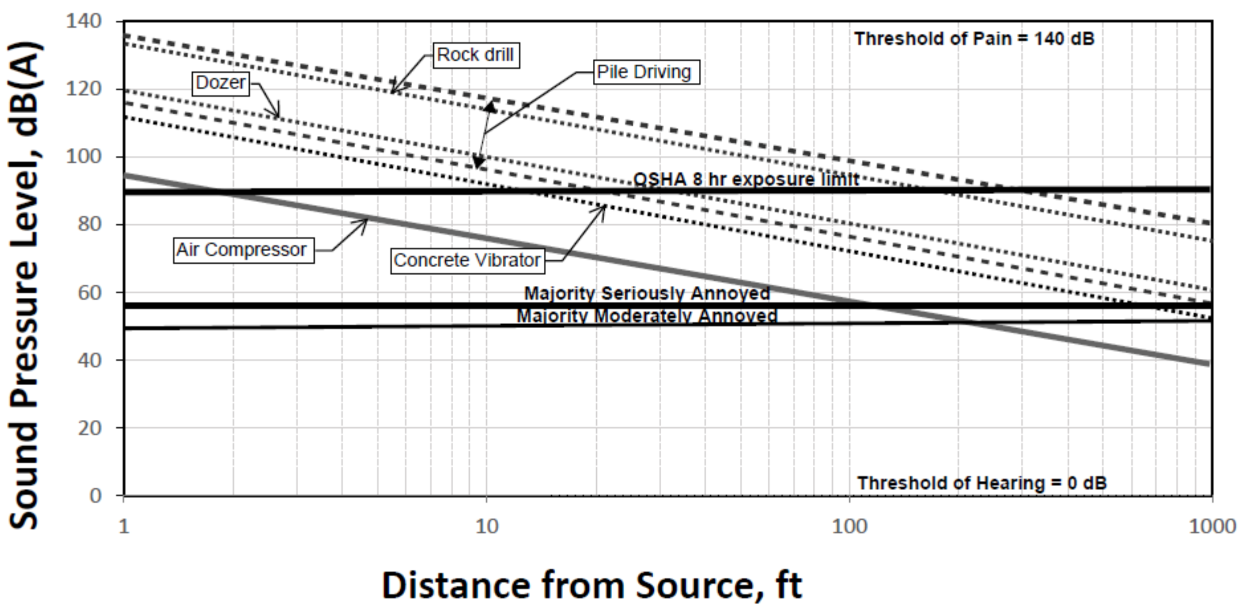


Figure 2 Typical ranges of measured sound pressure level vs. distance for various construction equipment

Noise from pile driving rarely, if ever, produces structural damage. However it causes annoyance that may reach a long distance. Figure 2 summarizes some typical data on noise levels for various construction activities. It also shows some of the criteria used to limit noise. The measurement of sound level is in weighted decibels, dB(A). OSHA set the eight-hour time-weighted average permissible exposure limit to noise at 90 dB(A), a limit which is also referred to a 100 percent "dose" noise exposure. OSHA uses a 5 decibel exchange rate (the number of decibel increase that leads to a halving of allowable exposure time), hence a time-weighted average exposure of 95 dBA is equivalent to a 200 percent dose. Studies from the World Health Organization have shown that many people become moderately annoyed by steady, continuous, sound levels above 50 dB(A) and seriously annoyed at continuous sound levels above 55 dB(A). For example, for the noisiest pile driving hammer, one would have to be more than approximately 300 feet away from the hammer to get the OSHA eight-hour exposure limit (90 dB(A)) and several miles away to drop below the threshold causing moderate annoyance.

Regulatory bodies and project specifications have become stricter in their requirements to control vibration and noise levels. Some sensitive buildings may require vibrations levels to be kept below 0.2 ips and noise levels maintained below 70 dB during parts of the day. Many project specifications include requirements for real-time monitoring to help achieve these levels.

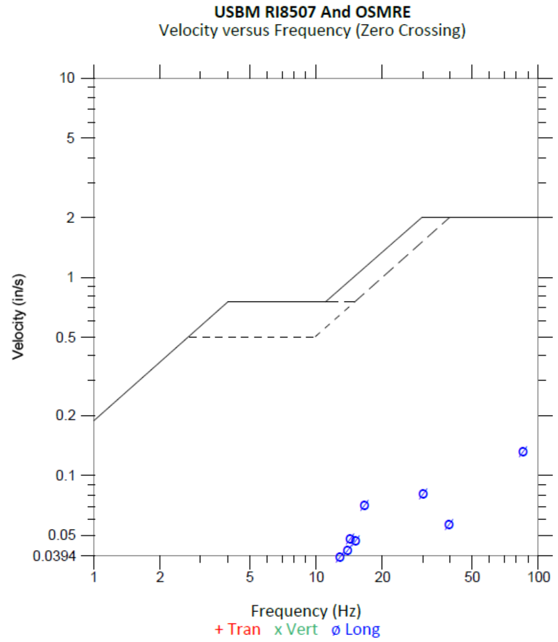
In order to mitigate the effects of vibrations and noise of a construction project, and also to reduce annoyance of adjacent owners, a few steps can be taken. These steps include **abating** vibration and noise, **educating** the various parties, keeping the parties **involved** in the construction process, and staying **proactive** in managing vibrations and misinformation. However, one of the most important steps is to **actively monitor** the vibration and noise levels of a construction project so the construction activities can be managed to keep these levels below project limits. These hard data together with the data presented in the previous sections, can help demonstrate that the work performed is below harmful levels and allow for adjustment of the work processes to correct any problems if measurements exceed acceptable thresholds.

How to monitor remotely?

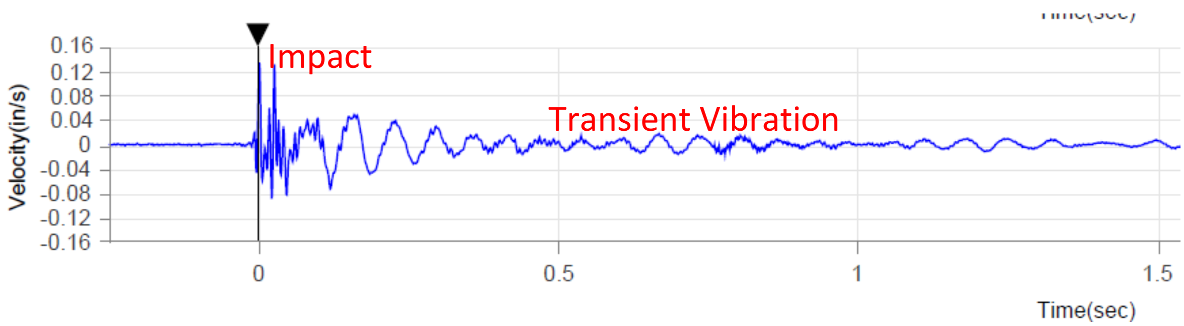
New technologies now allow us to perform vibration and noise monitoring remotely via advanced sensors, internet-based data transfer and web interfaces to visualize data so proactive mitigation measures can be taken immediately.

Various types of sensors exist to monitor vibrations. Instead of measuring only maximum PPVs per 15-minute interval, modern equipment can measure and record the entire time history of vibrations that exceed a threshold so that the frequency content can be considered when deciding the potential impacts of vibration to structural damage and to human perception and nuisance. The time history record allows the different components of vibrations to be examined to help determine what type of activities are causing them. Even in areas where no power or cable internet is available, cellular internet service and solar power can assist in deploying a sensor in practically any location at low cost. Figure 3 shows an example of a solar powered seismograph, a recorded time history, and a plot showing PPVs vs. predominant frequencies estimated using the recorded vibration time histories . This level of data detail is very useful in helping to protect project owners and contractors from potential claims against their means and methods.

Example solar-powered seismograph



PPV vs. predominant frequency of vibrations overlayed on the United States Bureau of Mines criteria



Example recorded velocity time history

Figure 3 Example solar-powered seismograph, recorded velocity time history and predominant frequency of recorded vibrations

Increasingly, vibration and noise monitoring is just one part of the monitoring requirements for a project. Collecting and managing the data from a variety of instruments and doing so in real-time to stay on top of the project can be a significant effort. In order to make the data collection, visualization and evaluation efficient and in near-real-time, Geocomp developed iSiteCentral® which provides a unique opportunity to perform real-time web-based vibration and noise monitoring. Figure 4 shows how iSiteCentral® can be used as a central data management system to collect data from vibration sensors and other relevant sensors or sources, store them, visualize them and provide fast and secure access to different user groups.

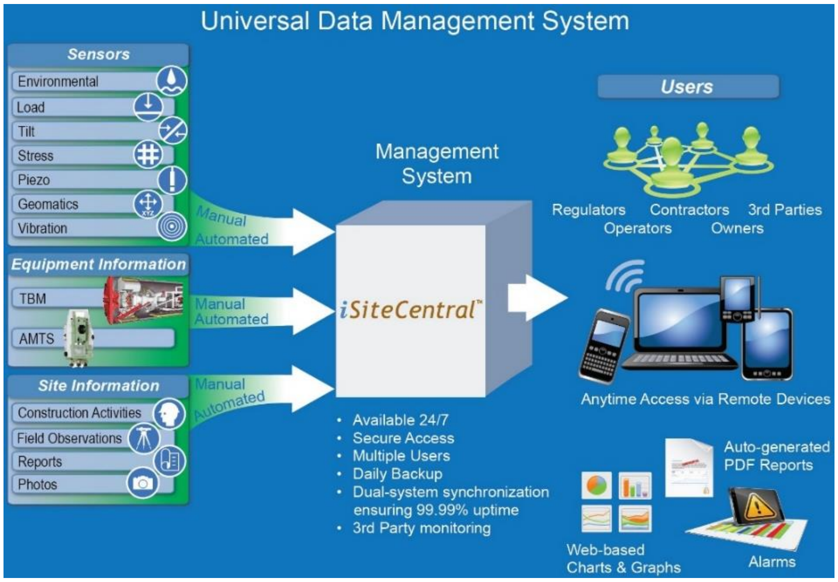


Figure 4 Data management approach in Geocomp's iSiteCentral®

iSiteCentral® provides valuable performance data from sensors and information which inform owners of the impacts that everyday operations, maintenance, repair and replacement have on structural health. Real-time changes can be tracked with automated alerts by setting up warning and serviceability limits on data. iSiteCentral® provides insights that can be integrated into maintenance and structural management systems to ultimately increase the quality and cost effectiveness of decisions for asset management. Some of the key benefits of this architecture are:

- Users can receive automated alerts, real-time data and informative reports and analysis. These are actionable performance data that can be accessed on any internet enable device.
- A geographical information system (GIS) based interface is accessible 24/7. The GIS interface allows for easy visualization of alert levels and ill-performing sensors and provides actual recording data in an easy and reliable manner.
- Warnings can be based on not only vibration sensors but also on potential effects of these vibrations such as potential settlements or pore pressure increases that can compromise foundations.
- Various types of reports can be generated automatically for management and for compliance.
- All information can be viewed with a common interface on a cell phone, a tablet, a laptop or other web enabled devices which provides users with immediate access to data in a rapid and convenient manner.
- The detailed time history of a vibration or noise event can be seen on the device to help identify the source of the offending event so it can be remedied quickly.

What lies ahead?

Traditionally only one or two accelerometers or geophones (velocimeters) might be installed on a project and the data recorded for later analysis. But increasingly, data management platforms such as iSiteCentral® allow project owners to use additional sensors to directly monitor the effects of any vibration exceeding some predefined threshold from instrumentation such as settlement gages, automated total stations or live video recording and do so in real time on their devices located anywhere. The use of these technologies can provide faster responses to control exceedances and reduce false alarms. These technologies also provide greater safety to owners since they can remotely monitor a full range of critical conditions without sending people to the construction site.

Traditionally, vibration monitoring involved recording maximum PPV for pre-specified time intervals, such as every 15 minutes. Today's sensors allow for recoding and evaluating the full vibration time history, which has multiple uses. Structural damage correlates to the predominant frequency of the vibration. Settlement caused by vibration induced densification depends on the number of loading cycles. Moreover, the frequency content can help identify the source of the vibration even in the absence of other field or photographic records.

This constant stream of data from multiple sources can also allow for live analysis and predictive estimation, such as evaluation of resonance effects, potential for vibration induced densification and direct development of site and equipment specific attenuation curves that can be used for other parts of the ongoing project.

These technologies help educate the community of the real effects of vibrations and noise while providing valuable measures for the contractors to establish and control abatement programs. We look forward to continuing to develop and apply these technologies to benefit owners and contractors.

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