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Continuous Monitoring of Hospital Construction Noise & Vibration

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ABSTRACT

During the demolition and construction phases of a hospital expansion and parking garage project in suburban Washington, DC the prime contractor established a continuous monitoring program of both air-borne noise and ground-borne vibration in several locations surrounding the site and within the existing hospital. The hospital continues to operate under a special exception waiver in a residential zone where historically residential neighbors have been very sensitive to, and very vocal about, noise emission from hospital operations, strongly resisting further hospital expansion. Knowing this history, the general contractor thought it prudent to hire an acoustical engineering firm to constantly monitor noise and vibration 24 hours a day, 7 days a week to establish a record of all noise and vibration activities around the site including that generated by construction for comparison to local and national codes and to be able to intelligently address noise complaints as they arise. Monitoring inside the hospital also provided feedback of the impact to a sensitive surgical suite near the construction site. This paper provides an overview of the many benefits of constant monitoring during the life of a construction project and the challenges facing consultants and engineers in setting up instrumentation, monitoring these parameters and interfacing with contractors, hospital owners and neighbors.

1 INTRODUCTION

The advent of Integrating Sound Level Meters with Logging Capabilities and the ability of transmitting digital sound data over cellular telephone networks opened a new chapter to the construction noise monitoring industry, enabling unmanned monitoring of the various construction activities that are constant and on-going. The recording of data is limited only by the longevity of the power supply, the stability of the equipment and its durability under all weather conditions. In the past, manned surveys on any given afternoon captured sound levels for the activity on that afternoon only, but now data can be recorded 24/7 for continual surveillance. Sounds great, but the complexities of configuring the modem and the concept of “just streaming the data via a cell phone connection” can still be overwhelming. For continuous monitoring, there is also the problem of providing power to the instrumentation over many months of operation and the ever-present question, “Is this financially beneficial?”

One of the big advantages of constantly streaming data to a web-based application is that the acoustical engineer can be notified immediately if any noise threshold has been exceeded. Job site supervisors can be expeditiously notified of the violation and lower the noise level if feasible. But having a system in place to monitor these signals and informing the job site in an efficient, automated fashion might be beyond what the typical acoustical consultant is capable of configuring in an economical fashion.

Additional struggle found along the way was that of long-term contract considerations with a major construction firm. Typical acoustical engineering contracts in the past were short-term, typically less than two months, now there would be the need for bonding, additional insurance and cash flow issues to consider.

In this particular example, both noise and vibration were required to be monitored during the demolition of existing structures and construction of the new building.

2 METHODOLOGY

The instrumentation challenges of compiling equipment to measure the data, stream it to a web-based software, analyze the data and contact the stakeholders involved in the construction process have been tackled by several instrumentation manufacturers who address these jobs on a variety of levels. In this instance, noise and ground borne vibration were required to be monitored and reported. Although monitoring over pressure levels and ground vibration is a common practice for blasting events, this particular project required more complex noise data than is typically expected.

2.1 Proposed Solution

To address system requirements Phoenix Noise & Vibration worked with Brüel & Kjaer Instruments to provide not only the measurement and power supply hardware for the system but also the wireless modem connection, web-based application capable of identifying exceedances, sending notifications, and generating reports. The Noise Sentinel system is composed of a dedicated sound level meter and vibration monitoring device with wireless modem which streams data to the web-based Sentinel application. Power to the unit is provided by either solar panels which charge deep-cell marine batteries or mains power. One benefit to the Brüel & Kjaer system is the ability to trigger an audio recording of noise events which exceed a certain threshold. This could be greatly beneficial in noise source identification since all the monitoring would be unmanned; high noise events could be played back at any time after the event to determine the source of the noise. All the instrumentation would be available on a rental basis and would be shipped to the site and installed by knowledgeable Brüel & Kjaer staff, familiar with the equipment.

2.2 Instrumentation

The onsite instrumentation includes the following:

1. Integrating sound level meter with outdoor microphone
2. Vibration monitoring unit with triaxial accelerometer
3. Wireless modem
4. Power management
5. Deep cell marine batteries (solar only)
6. Solar panels
7. Weather proof instrumentation case
8. Weather proof battery case (solar only)
9. Mounting hardware

The equipment is mounted 2 to 3 meters above grade on a metal pole, with a 100 mm diameter. The pole is set in concrete.

The renters of the equipment are usually required to provide a cell phone account (SIM card) with a static IP address and a data plan, which is an additional cost outside of the rental fee for the instrumentation.

Monthly cost for the instrumentation is extremely reasonable and comparable to the flat-rate rental of an Integrating Sound Level Meter. The rental rates are on a sliding scale and, as one would imagine, dependent upon the number of points being monitored and the length of the rental period.

Figure 1 Instrument Setup on Pole. Note microphone & cellular antennae.

2.3 Installation

Brüel & Kjaer provides onsite installation of the instrumentation which takes between one and two days per point depending upon the complexities of the site, power source used (solar or mains). Clearly if mains power is available at the site, this is the cleanest way to power the units. Plug them in and let them go. The solar power option comes with its own complexities including sufficient solar exposure, determining the number of batteries required and the impact of varying ambient temperatures. Overhead trees or nearby buildings can severely impact the location of a working solar unit. In one instance additional batteries were required to account for the lack of sun exposure and short winter days. A typical solar-powered instrument setup is shown in Figure 2.

Figure 2 Solar-Powered Instrument Setup

One beauty of the system regarding power is the internal batteries of the monitoring unit (solar-powered or mains) which allow the instrumentation to continue to measure and store data in the event of a power outage. This proved very valuable early on when working through the setup of a fussy solar powered unit. No data was lost due to the presence of the internal batteries.

The biggest apprehension of setting up such a system was the wireless modem/data streaming piece. Again, this was completely handled by the equipment supplier, but the challenge was to get third party equipment that was robust enough to weather the long term of the measurement plan. This turned out to be one of the weakest links in this measurement chain.

Planning of the instrumentation setup is critical. Determining the locations was based upon input from the critical stakeholders: the acoustical consultant, the general contractor, and the hospital. Solar units require good exposure to the sun, microphones need to be in good, unobstructed proximity to the construction site, contractors need the units out of the path of construction equipment, and the hospital administrators walk a fine line between their desire for the service and their reluctance to pique their neighbors' curiosity. A solid site plan showing measurement locations needs to be established early on in the project with each measurement location identified. A precise, simple, logical naming scheme should be used to identify the points. Each point gets a fixed name,

Figure 3 Accelerometer stud mounting in ground poured concrete

rather than each instrumentation setup since the instrumentation might move through the life of the project.

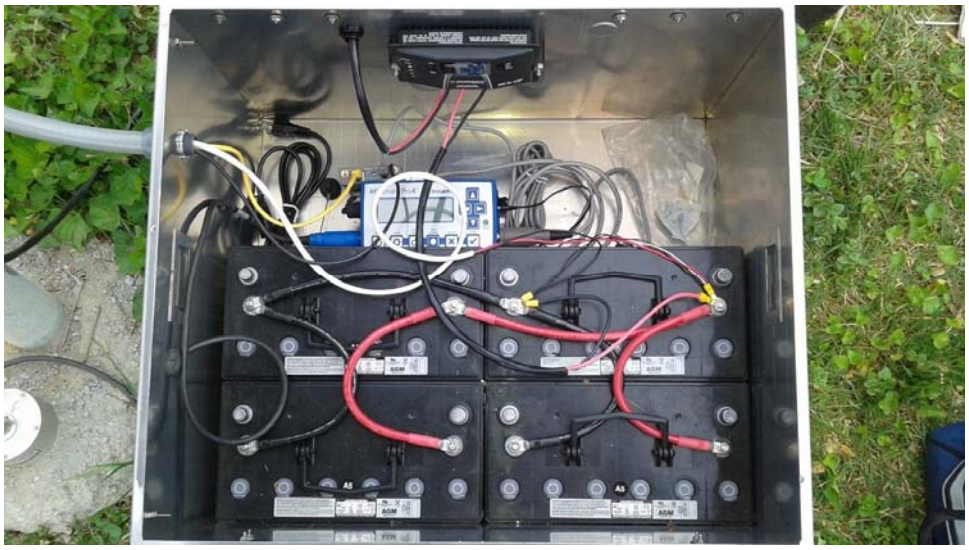

Figure 4 Deep cycle marine batteries charged by solar panels

On this project all instrumentation was mounted outside with the exception of one location. The contractor specifically requested that noise and vibration be measured inside the hospital in an area where foundation work was required at the base of the existing building. Patient rooms and vibration sensitive operating theaters were in this area. To keep equipment out of the hospital's way while monitoring the sensitive areas, instrumentation was place in the ceiling plenum of a corridor. This involved running power to the equipment, constructing a shelf to hold the instrumentation, mounting the accelerometer to the underside of the slab and making sure the wireless modem had a strong cell signal. Photographs of the shelf and accelerometer mounting are shown in Figure 4.

Figure 5 Interior measurement setup adjacent to an operating room, ceiling plenum equipment shelf (left) and under slab accelerometer mounting (right).

Due to the sensitive nature of the hospital use (this was the corridor just outside a patient room) plastic sheeting would be draped and taped every time the ceiling plenum would be accessed, adding to the difficulty of indoor monitoring.

2.5 Relocation

Ideally the number of monitored points is sufficient to provide a good understanding (or coverage) of the noise and vibration emanating from a construction site in all critical directions however budget constraints will typically govern the total number of points to be monitored at any given time. Through the life of the subject project a total of eight separate noise monitoring locations were desired, however only five were necessary at one time. This required relocation of the instrumentation midway through the project. This can be provided by the instrumentation supplier (at additional cost) or by the acoustical consultant at their own cost if the consultant has the know-how of the system set up and operation.

2.4 Noise & Vibration

The system works and works well! Once the system is up and running one can log on to the Noise Sentinel Website and easily access real time noise data, the last hour's activity, the last day's activity, the (last?) current week's activity (1 hour Leq) and the last month's activity (24 hour Leqs) at each individual location. The recorded "audio clips" can easily be listened to with a few mouse clicks. Customized reports can be generated ad hoc or standardized and scheduled for regular delivery to stakeholders at any desired interval. Currently the vibration data cannot be streamed continuously to the website but is available primarily through the reporting function of the website. This is clearly one of the downsides of the current setup. It is understood that hardware is being developed which will allow real time access to vibration data as is currently available for noise data. Notification of alerts, both noise & vibration, are readily sent to stakeholders via email or SMS.

2.5 Contracting

Additional challenges found along the way involved bonding and cash flow. The typical business model for noise measurement by an acoustical engineer consisted of writing a proposal, carrying out the service, writing the report, and collecting a fee, usually a very short-term endeavor (less than 2 months). Typically a professional liability insurance policy was the only requirement prior to approving the contract and completing the job. Dealing with a major construction firm brought with it a long-term contract and the need for the purchase of a Payment and Performance (P&P) bond. While the cost of the P&P bond was charged to the client, it entailed a rather lengthy approval process and procuring the bond involved many "non-billable" hours by the acoustical engineering firm. Regarding cash flow, it is typical for construction firms to retain up to 10% of all payments for services rendered by subcontractors until the completion of the contract. Construction contracts can easily extend for more than two years resulting in a significant holdback of the subcontractor's fee. In our case this retainage complicated the business model in that a significant amount of the fee came from rental equipment which was billed on a monthly basis and had the potential to negatively impact cash flow.

2.6 Reporting

Reporting included noise and vibration levels for each day through the previous week at each measurement location. The Brüel & Kjaer system offered lots of variability for reporting, giving as much or as little as the client or consultant wanted. In this instance, automatic reports were generated on a weekly basis, issued late Sunday night and delivered via e-mail to the acoustical consultant and the prime contractor for their review every Monday morning. The prime contractor requested NOT to have alerts for exceedances through the week in the form of emails or text messages. The contractor's confidence was in the acoustical consultant to pull data quickly if a resident complained about noise or had fears about vibration levels. Shutdowns and lawsuits are expensive and effective communication to assure concerned residents is priceless. The acoustical consultant is sandwiched between the prime contractors who are not noise experts and Brüel & Kjaer, who will provide any data desired and the instruments to collect it, but wants little to do with interpretation and nothing to do with prime contractors or complaining neighbors. The acoustical consultant and the data act together as a shield, a layer of security, when residents raise issues that distract the contractor. As an example, when residents complained to both the hospital and prime contractor about concerns over vibration levels, the consultant analyzed the data and arranged a conference call including all parties. The residents were fearful of structural damage to their homes because of episodes of vibration during construction and their new found awareness of structural damage caused by the 2010 earthquake in their community. and assured the residents that not only was the vibration level not near the earthquake level, but it hadn't even reached the threshold of damage for structures established by the U.S. Bureau of Mines (USBM) Criteria for Structural Damage to Buildings Due to Ground Borne Vibration.

3 CONCLUSIONS

Timely retrieval of noise and vibration data is crucial when neighbors bring forth concerns about the impact of construction vibration on their buildings and the impact of construction noise on their day to day lives. The continuous noise & vibration monitoring acts as a concrete record of performance to substantiate adherence to codes and when there is evidence of excessive noise, steps can be taken to mitigate . The savvy noise consultant can use the data to educate and reassure the neighbors while the prime contractor focuses on bringing the project to completion when the construction noise and vibration will then be nothing but a memory. Both Brüel & Kjaer reps and our consultants note that many prime contractors show no interest in the 24 hour monitoring reports or the immediate notifications until a neighbor complains, and when they do, the data is wanted immediately. If the system is planned well and carefully installed, it works well after it is established. When the supplier of instrumentation responds quickly in addressing and fixing problems, whether they be hardware or software related continuous monitoring is reliable; it is a valuable tool for the acoustical consultant and worthwhile for the prime contractor and building owner.