The Evolution of Environmental Ground Borne Vibration Measurement, Assessment and Reporting Over the Last 50 Years

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1 Introduction

Urbanization has increased the proximity of residential development to sources of environmental ground borne vibration, including at and below grade rail, construction activities, quarries and heavy industrial processes. Measurement, assessment and reporting on ground borne vibration induced by these sources have always been an integral component of acoustical consulting practice. This retrospective highlights the evolution of measurement equipment and reporting techniques over the last 50 years. Often, changes to the methodology are driven by new or modified regulatory guidelines as opposed to advances in available technology. Other factors, such as capital costs and efficiency are also considered. Limitations in current measurement and reporting methodologies give an indication of where improvements in technology may be made to environmental ground borne vibration assessment in the future.

2 Discussion

2.1 1950s to early 1980s

In the early 1950s, the issue of environmental vibration relative to perception and comfort were not of particular concern. Most monitoring focussed on activities that generated vibration capable of structural damage such as blasting at quarries. A good example of this is a 30 year long monitoring program at a quarry in Ontario of weekly blasting activities. There were few regulations at that time and the project was initiated by the quarry owners in case of future complaints. The results of these measurements were analysed and compiled in reports issued yearly.

These measurements were done with a portable seismograph, the Cambridge vibrograph, shown in Figure 1. The Cambridge vibrograph etched directly transmitted vertical movements on celluloid tape with a stylus. The celluloid drum was driven by an internal wind up clockwork. There was no need for a power source, which for a portable unit, was beneficial. The amplitude of the recorded movements were reduced by 10 to 50 times and could only be seen using a simple microscope. This made checking results in real time impossible. A timing signal and an electrically operated event marker would also be noted on the celluloid alongside the deflection trace. The vibrograph was capable of measuring 10 to 100 Hz but could be extended down to 1 Hz.

Given that the movements were directly measured, the vibrograph itself had to be set up at the measurement point which would have been a concrete monument. Since remote measurement was not possible, there was an inherent risk to those operating the equipment, particularly when measuring quarrying activities in close proximity.

The measurement, analysis and reporting procedures were all done by hand and were time consuming. Reports were book bound and either hand typed or sent out to be published.

Surprisingly, the methodology for these measurements remained largely unchanged over the 30 year period. A second less sensitive Leet seismograph was added in order to measure two locations in 1956. It should be noted that even in the 1950s, the Cambridge vibrograph was not cutting edge technology. Nonetheless, it was robust and functional and there was no impetus to invest additional funds in new equipment.

It wasn't until 1974 that the Cambridge vibrograph was replaced with another seismograph, the VME Velocity Recorder. The VME had an external geophone and using a mirror galvanometer, recorded results on photo sensitive paper. The drawbacks to this seismograph were the limitations (and weight) of the internal rechargeable battery, the expense of the photo sensitive paper and the short measurement duration of 60 seconds.

The early 1970s also saw the beginning of the use of the metric system, although the earliest reports referred to metric as a fashion and not yet a standard. Reports through to the early 1980s were still hand typed and most results tabulated in the same fashion as the previous 20 years.

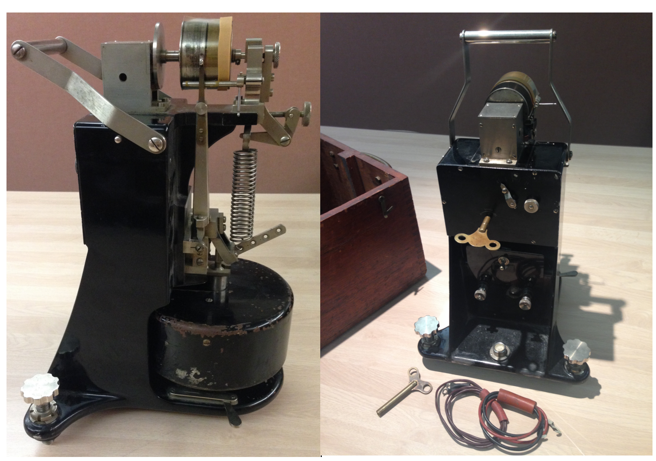

Figure 1: Cambridge Vibrograph

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2.2 Early 1980s to mid 2000s

In the early 1980s, railway authorities - Canadian Pacific (CPR) and Canadian National (CNR) - started to develop their own land use guidelines for new development adjacent to railways. These included criteria for railway induced ground borne vibration. A boom in new residential construction meant that railway vibration studies became a larger part of acoustical consulting.

The older seismographs were not particularly useful in this application. Thus, new equipment was acquired in order to adequately measure and assess vibration from railway train passbys. The methodology of choice was to record the signal from vibration velocity transducers. Initially this was done on analog devices, a Nagra IV-SJ and more frequently, a Sony Beta tape recorder. This transitioned to a digital recording device in the late 1990s.

The recordings had the advantage of providing two channels on which the signals from two transducers could be recorded simultaneously. The recording would then be played back and analyzed in the office. Time histories were produced using the Metrosonics Chart Recorder and if octave band vibration velocity levels were required, the signal was run through the Brüel and Kjær 1233 Real Time Analog Frequency Analyzer. See Figure 2.

Early on, the data output would be manually recorded off the screen of the Frequency Analyzer for inclusion in reports. However, the early 1980s was also the beginning of the age of personal computers. A newly acquired Osborne1 portable microcomputer provided an interface that could directly output the octave band data in graphical presentation. Computers in the office also meant that reports were no longer typed but prepared using word processing programs.

Similarly to the previous twenty years, the methodology of measurement and assessment remained largely unchanged until the turn of the century. The Osborne1, Chart Recorder and Frequency Analyzer, long obsolete yet still functional, remained in service for this sole purpose. Again, there was little impetus to invest funds in new equipment.

Figure 2: Brüel and Kjær 1233 Real Time Analog Frequency Analyzer (left) and Metrosonics Chart Recorder (right)

2.3 Mid 2000s to today

Although old technology at the time, the new millennium finally brought forward a jump to "direct to hard drive" analysis for vibration measurements. The LMS Pimento system included a front end A/D box (which provided not only the converters but also the biasing output) as well as a back-end software application to manage data capture, storage, and post-processing. With the implementation of time domain and frequency domain processing, the analysis possibilities were essentially endless. However, with the new applications and possibilities came new challenges. Laptop computers became an integral part of the measurement signal chain and as such needed to be purchased and managed. Software licensing became a key component of the overall system as "pay-for-functionality" was now part of the commercial landscape for equipment manufacturers. And of course, transporting and powering the entire data acquisition system was a logistical puzzle.

Later in the decade, the City of Toronto recognized the potential adverse impact that construction vibration could have on neighbouring structures and enacted the "Construction Vibration By-Law" (514-2008)[1]. The By-Law required that any building which could be negatively impacted by adjacent construction (as defined in the By-Law) be monitored for vibration according to a specific set of frequency-dependent criteria. With the By-Law came a further equipment boom with companies previously known for blast vibration monitoring driving a new market in construction vibration monitoring equipment. The blasting equipment brought with it advances including powerful onboard processing, full-time cellular connectivity, and real-time notification of events over a given threshold. Owing to its blasting roots, the equipment was also extremely durable and portable with long-lasting onboard batteries (although the cellular modems meant that AC power was still required).

2.4 Future

Demands for new advances in equipment are constantly arising. Construction specifications are being written with more and more stringent vibration monitoring requirements and often include criteria which require new flexibility in equipment operation. Based on the current trend, the equipment of tomorrow will likely be:

- Wireless with central data collection and cloud connection for data transfer and processing;
- Durable and portable;
- Long on battery life and may include alternate power supply options;
- Low-cost on a per-sensor basis to allow more discrete measurement points;
- Powerful with regard to onboard processing and rapid data presentation.

3 Conclusion

Measurement, assessment and reporting on environmental ground borne vibration has changed significantly over the last 50 years. However, the integration of new technology into acoustical consulting practice is highly influenced by changes to regulatory guidelines as well as capital cost.

References

[1] City of Toronto Municipal Code, Chapter 363, Building Construction and Demolition, Bylaw 514-2008.