Event 2015 — A.A. Editor and B. Editor (eds)
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The Use of Microseismic Acquisition for Vibration Monitoring Applications

Submitted to the Field Measurements in Geomechanics conference – Sydney 2015.

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Abstract

Microseismic monitoring is a critical tool that is widely used in the mining and petroleum industries to provide information about changing stress conditions of the rock mass. The equipment is also readily applicable to geotechnical applications, such as railway, structural and blast monitoring.

In this paper a comparison is made between two types of blast monitoring units. Blast and vibration monitoring units can seamlessly integrate with existing seismic monitoring systems or be deployed independently. The versatility of the systems are discussed with examples from three recent applications. The first application shows how, in the near-field, sensors have been used to help engineers optimise blast sequences and quantify the effect of blasting on nearby ground support. The second and third applications show the application of microseismic sensors, in publically sensitive locations, to monitor vibrations generated as a result of mining activity or industrial power generation units to ensure they do not exceed locally recommended guidelines.

Vibration and blast monitoring systems are an easily deployable hardware and software package that can successfully recorded near-field or far-field vibrations, providing operators with useful information for each application.

1 Introduction

Microseismic monitoring is used throughout the world to monitor small, and sometimes large, seismic events resulting from mining activity. Installations in both underground and open pit mines accurately locate seismicity as it occurs and alerts operators to abnormal activity. (Collins et al. 2015) show some of the recent improvements and capabilities of seismic software to perform real time and advanced analysis that provide operators with useful tools to get the most from their seismic data. Microseismic hardware has the capability to monitor vibrations across a wide range of frequencies and is becoming more commonly used in geotechnical applications, for example (Collins et al. 2014) present data on a rock fall monitoring system used in the railway industry. In some cases the vibration monitoring units are being used alongside microseismic mining installations, while others run as individually isolated units.

Blasting in mines generally occurs on a daily basis and can induce strong vibrations into the rock mass. For mines located near to a residential areas the possibility of causing damage or disturbance to neighbours is of concern, as well as the possibility of damage to the much closer mine buildings and infrastructure. Similar vibration concerns are seen for geotechnical applications that induce strong vibrations. (Mohanty et al. 2014) show that blast efficiency is often less than 40%. By optimising their blasting methodology, it is thought that operators can minimise blast costs as well as ore dilution.

Current blast monitoring technology is capable of detecting the peak particle velocity (PPV) of blasts and the corresponding air blast if occurring near surface. However, many of these monitoring units are based off of trigger based technology that can result in data gaps. ESG has incorporated its continuous recording capability into a blast monitoring solution meaning preset trigger settings are not required and all activity detected by the sensor is recorded. This paper focuses on three case studies in different vibration and blast monitoring applications.

2 Blast Monitoring Solution

Case study one presents a new blast monitoring solution (ESG Solutions 2015) that enables operators to quickly analyse blasts and quantify the blasting efficiency. By analysing the trends of their blasts, operators are able to optimise blast techniques to minimise blast failure or improve energy release.

A two month field test in and underground mine was performed comparing the new blast monitoring solution against a standard system that is used in the industry. Figure 5 demonstrates the PPV recorded by both units has good agreement. However, the continuous recording ability of the new system enabled the detection of all blasts whereas the trigger based technology of the standard instrument missed approximately 30% of the blasts.

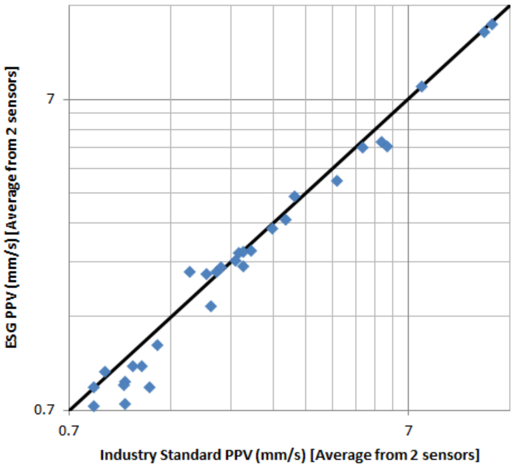


Figure 5 A comparison of PPV for blasts recorded by both units. A clear linear relationship is seen between the events.

Expected blast design time information can be uploaded and compared with the actual onset times of the blast sequence. The result can highlight blast holes that misfired or failed to yield their optimum energy. Figure 6 shows an example blast sequence with notes and sub blasts picked.

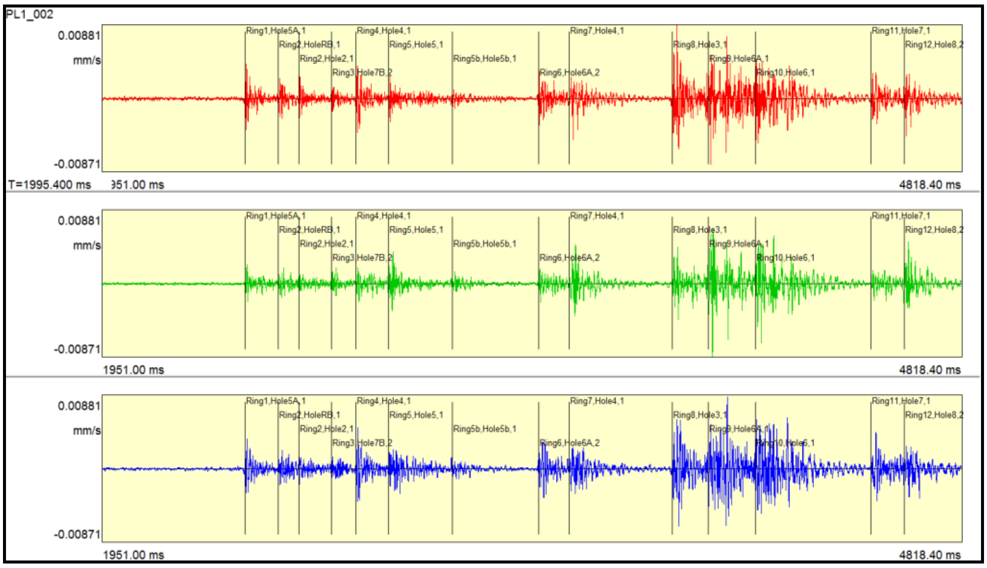
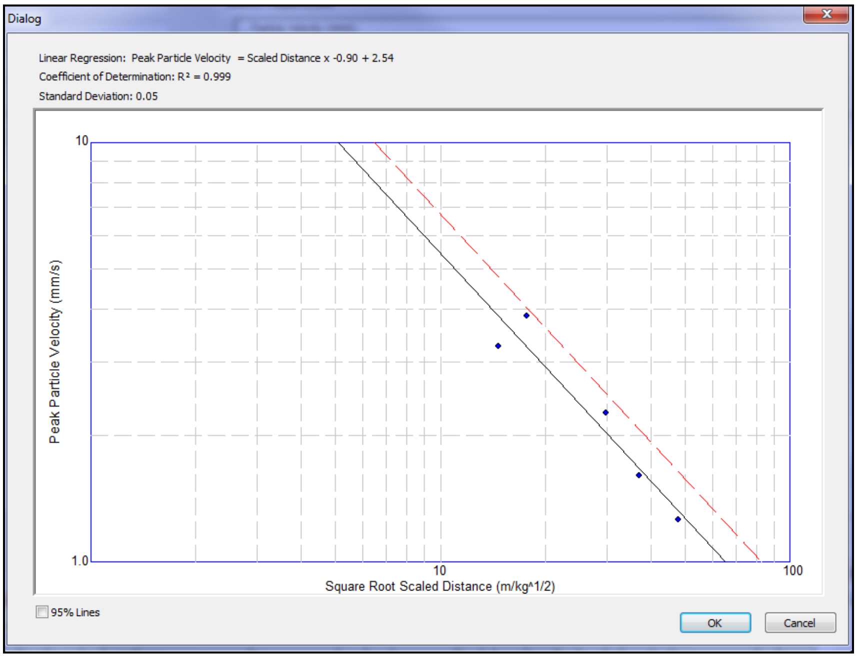


Figure 6 **A blast sequence with sub blast times loaded onto the trace. Vertical lines indicate expected blast time, and a note is shown over each line indicating its order in the sequence. A good correlation is seen between each trigger and the corresponding initiation of the blast.**

The PPV for each individual sub blast can be calculated and normalised by accounting for the blast weight to determine the efficiency of each sub blast. The automatic cataloguing of each blast allows for a PPV and scaled distance relationship to be determined over time, as seen in Figure 7. The relationship allows a user to calculate a PPV from a blast charge (in Kilograms) and distance, to determine the required support around a tunnel at that distance from the planned production or development blast.



Linear Regression: Peak Particle Velocity = Scaled Distance x -0.90 + 2.54

Coefficient of Determination: $R^2 = 0.999$

Standard Deviation: 0.05

Figure 7 **The relationship of PPV, charge weight and distance for multiple blasts.**

The blast monitoring solution has the capability of time synchronisation which, for surface monitoring or networked monitoring, allows multiple sensors to be synchronised and an estimate of location given. This may be of particular importance where multiple blasts are taken from different locations.

3 Vibration Monitoring Solution

The vibration monitoring hardware consists of a six channel high resolutions acquisition unit and externally connected sensor(s) that can be optimised to the application. Accompanying the hardware is a customised software package that ensures continuous recording of the system and suitable analysis of the data for the specified application. Two case studies are presented below.

3.1 Case Study Two – Vibrations Resulting from Power Generators

Small Islands often lack conventional large scale power stations and will often resort to using smaller power generation facilities. Case Study one monitors vibrations on a North Atlantic Island that relies on generators for electricity. Due to the relatively small size of the island, some residents are located within close proximity to the generators that continually run to support the island. The vibration monitoring system provides a solution to alert the operating company when ground vibrations begin to reach disturbance levels.

An example of the force balance accelerometer (FBA) used on site is shown in Figure 1. A portable Paladin^{TM} data acquisition unit is continuously recording vibrations recorded by the sensor.

Figure 1 The FBA sensor installed in its purpose built enclosure. The cable is installed at shallow depth to ensure the cable is not accidentally interfered with.

Customised software was developed that enables the data to be assessed in terms of the vibration dose value (VDV) as set out in the British Standard (BS 6472-1 2008). The vibration response was also assessed in terms of the narrowband unweighted RMS accelerations as set out in the British Standard (BS 6472 1992)). The narrowband unweighted RMS focuses on frequencies that maintain continuity between previous vibration measurements taken at various locations on site. There are three range threshold criteria for the VDV value: “low probability of adverse comments”, “adverse comments possible”, and “adverse comments probable”. Each range has a night-time and daytime threshold to take into account the publically expected lower noise threshold at night. Figure 2 below, shows an example of the VDV result going from below to above a defined threshold.

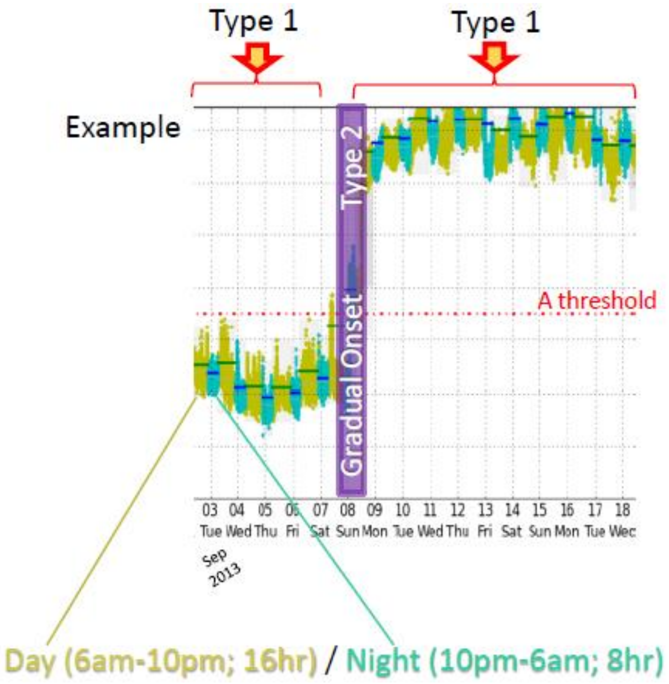


Figure 2 The VDV recording presented in the software showing night-time and daytime recordings; different types of vibration associated with the recording; and a threshold value.

Two types of signal were defined during recording; Type 1 – Uninterrupted measurements (BS 6472-1 2008), and Type 2 – Separate and prominent bursts of short-term vibration, or a gradual onset. Examples of Type 1 vibrations could be the sustained operation of the generators. An example of Type 2 data could be generated from turning on or off group(s) of generators.

The vibration monitoring system installed at site is able to identify the timings of significant environmental vibration exceeding the defined “acceptable level”. This enables the operator to optimise the two generators for maximum output and remain under the threshold for vibration complaints from the public.

3.2 Case Study Three – Vibration Monitoring Near a Mine Site.

Case study three took place at a hard rock mine in Canada where blast vibrations were a concern to public housing. A portable Paladin vibration monitoring system was installed in the basement of a residential house approximately 2.5 km from the mine. The optimal sensor for this monitoring solution was determined to be a 4.5 Hz Geophone based on the frequency band of interest. Due to the relatively large distance involved from the mine to the sensor the blast vibration signals were expected to be predominately low frequency due to attenuation of higher frequencies. It is also unlikely that signals will travel in a direct path from source to sensor due to soils close to surface resulting in slower P and S wave velocities. Continuous data recording of the sensor was essential for this project as blasts taken at the mine were not guaranteed to trigger the system.

The mine has a dedicated microseismic monitoring systems distributed throughout the mine infrastructure. The microseismic system is able to record events as small as -2.0 M_W while a Strong Ground Motion (SGM) sensor installed on surface at the mine means the maximum magnitude detectable is approximately 3.0 M_W. The three different sensor types enable a comparison of the same vibration source at different distances seen in Figure 3, in terms of PPV and frequency content.

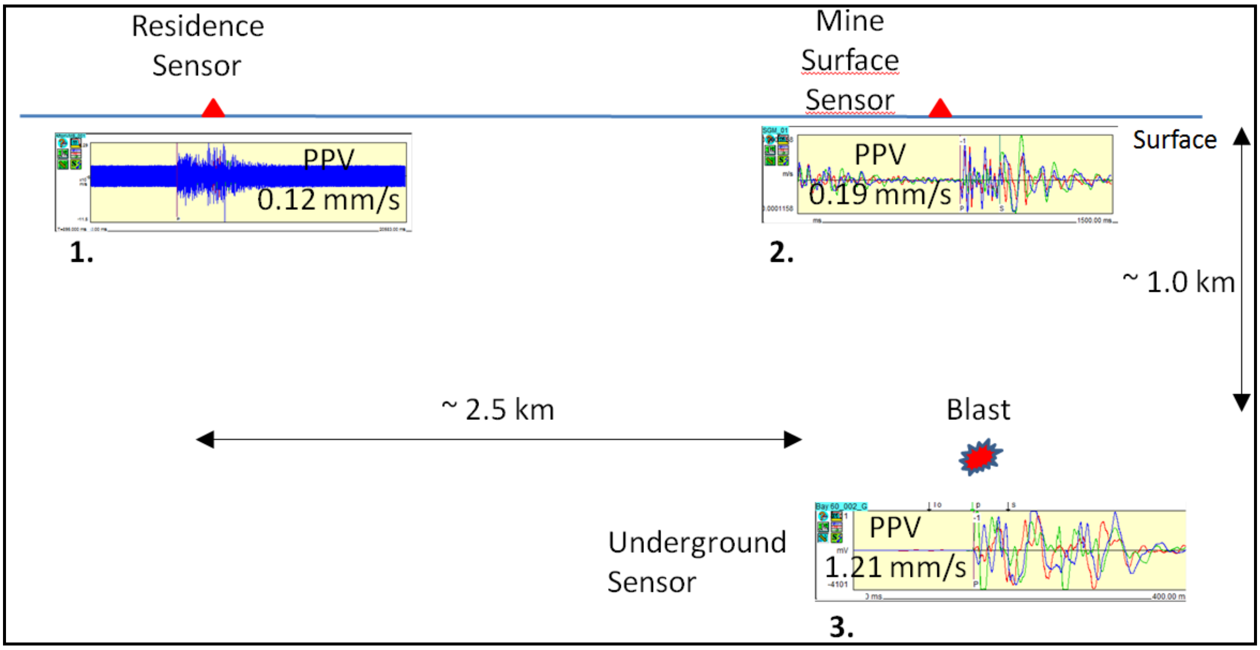


Figure 3 **Profile of a blast looking at the three different sensor responses. 1. The vibration response of the residential sensor approximately 2.5km from the blast. 2. The surface sensor response approximately 1 km from the blast. 3. The closest microseismic sensor to the blast, approximately 230m.**

The residential vibration sensor is responsive to naturally occurring and mining induced seismic activity. The continuous recordings were digitised and stored to a removable USB storage device to enable post analysis of the recordings.

Studies have shown surface amplification of vibrations can occur for multi-story buildings. (Siskind et al. 1983) show up to a 4 times amplification is possible in residential buildings. In general, federal governments as well as some local governments will have guidelines for the maximum peak particle velocity relating to blasting activity. Environment Canada stipulates that a maximum PPV of 12.5 mm/s for any frequency (Environment Canada, 2015) should not be exceeded at or beyond the mining property. The United States Bureau of Mines (USBM) has performed extensive studies on vibration induced damage and has stricter guidelines that take into account the more damaging effect of lower frequencies (Siskind et al. 1983). In this case study both guidelines were taken into account and implemented into the software.

Figure 4 shows the largest vibration recorded at the residence along with smaller blasts and some stomp tests performed for calibration purposes. The stomp tests were performed approximately 1m from the sensor. The largest blast (Bell blast) taken at the site resulted in a PPV of 0.12 mm/s with a dominant frequency of 27Hz. The stomp tests performed were approximately three and a half times stronger than the vibrations felt at the residence from the largest blast performed at the mine. Even accounting for a 4x surface amplification, the amplified PPV should not exceed 0.48 mm/s. The amplified PPV is at least an order of magnitude below the government thresholds for damage.

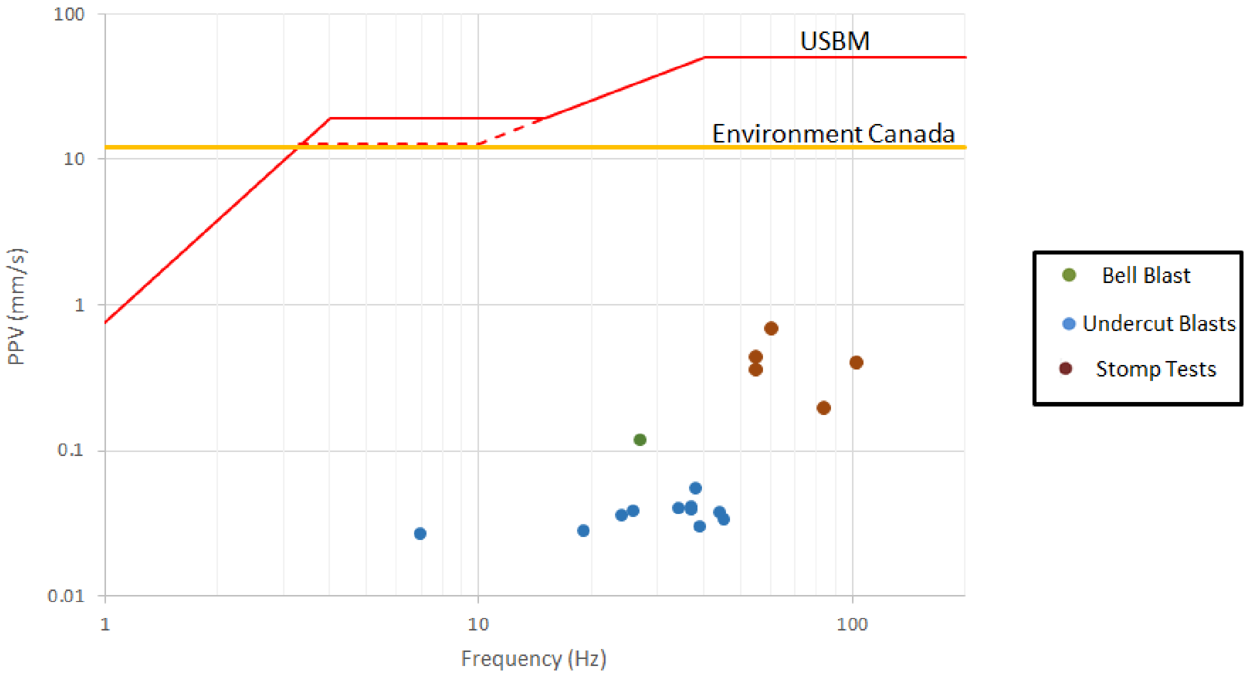


Figure 4 **The PPV is shown for the three different types of event; calibration stomps, smaller undercut blasts and a large bell blast. In all cases the PPV recorded lies well below the government guidelines for damage to occur.**

4 Conclusions

Three case studies are presented of blast and vibration monitoring applications in this paper. The application of the vibration monitoring hardware has uses in a wide range of applications such as exceedance level detection, optimisation and alerting/awareness. The hardware can be used in a variety of industries of which mining and geotechnical have been given as examples.

For mining applications such as blast monitoring, the system can be incorporated with existing seismic monitoring infrastructure to provide additional value to the system. As a standalone project in blast monitoring the system has the capability of time synchronisation if more than one unit is implemented. The goal of the system is to optimise the blasting methodology implemented in the mines with the aim to increase blast efficiency and be able to generate quantitative data for ground support requirements in the vicinity of blasts.

Geotechnical applications can include exceedance threshold monitoring of local vibration guidelines for disturbance. This can be from a blast source such as are used in a mine or quarry, or continuous vibrations from nearby power stations. In each of the above cases the blast or vibration solution that was presented, successfully monitored each application saving continuous data and ensuring no vibration data was missed.

References

Collins, D.S, Shumila, V, Butler, T, Hosseini, Z, Trifu, C.I 2015, 'Microseismic real time and advanced analysis in mines' , *International Society of Rock Mechanics Congress*, Montreal, Canada.

Collins, D.S, Toya, Y, Hosseini, Z, Trifu, C.I 2014, 'Real time detection of rock fall events using a microseismic railway monitoring system' , *The Association of Geohazard Professionals, Kingston, Ontario, Canada*.

Environment Canada, '*Environmental Code of Practice for Metal Mines –S.4-R.420',* viewed on 2 March 2015, https://www.ec.gc.ca/lcpe-cepa/default.asp?lang=En&n=CBE3CD59-1&offset=2.

ESG Solutions 2015, *Blast Monitoring User guide*, ESG Solutions, Kingston, Ontario, viewed on the 1st of February 2015.

Mohanty, B, Zwaan, D & Trivino, L 2014, 'Investigation of stope blast designs in a deep underground mine through vibration analysis' , *Deep Mining*, Sudbury, Ontario, Canada.

Siskind D.E, Stagg, M.S, Kopp, J.W, Dowding, C.H, 1983, 'Structure Response and Damage Produced by Ground Vibration from Surface Mine Blasting'*, United States Bureau of Mine*, Report of Investigation 8507.

Trifu, C.I, Shumila, V 2005, 'Analysis of Peak Particle Velocity and Acceleration Distributions at Darlot Gold Mine, Australia', *Rockburst and Seismicity in Mines*, Perth, Australia.