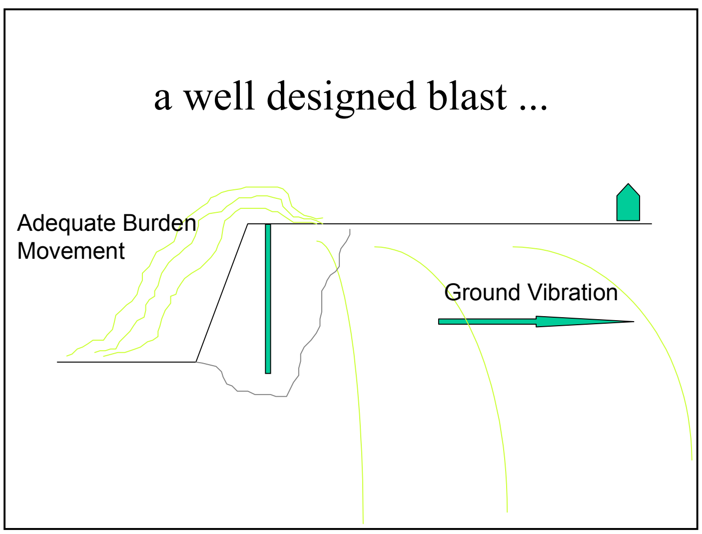
Blast Induced Vibration

In the world today a large percentage of the material used for construction is obtained through a mining or quarrying process. Typically, if a material or resource cannot be grown, it must be mined. This usually requires the use of explosives and blasting to efficiently excavate the raw material.

Most metal and non-metal mines must remove material that is over or on top of the primary mineral to be recovered. This over burden removal must in many cases be extracted in the same way the primary material is obtained. Drilling and Blasting is by far the most economical means to excavate this material. The initial blast design depends mainly on the hardness of the rock, the geologic structure of the rockmass, the location of the mine relative to vibration sensitive structures, available drilling equipment and the excavation rate and capacity of the mining equipment.

To begin, a well-designed blast consists of a quantity of explosives placed into a series of blast holes drilled into a rockmass. The amount of explosive energy generated by the explosives must be adequate to overcome the tensile



strength of the rockmass. This series of blastholes must then be detonated in a controlled sequence as to control the burden and spacing dimensions between adjacent holes. A well-designed blast will efficiently utilize the explosive energy in order to result in optimum fragmentation and burden movement. One of the negative impacts of blasting is ground and air vibration. Proper burden spacing design dimensions maintained through accurate field controls typically will yield reduced ground vibrations as the energy is used to fragment and move rock and **not** to create excessive ground vibrations through energy over-confinement.

Vibrations generated by blasting that are transmitted through the ground are typically referred to as elastic vibrations. These types of vibrations are non-deforming vibrations as the rockmass or transmission medium will return to it's normal state after the vibration has passed. Elastic ground vibration is wave motion emanating outward from a blast much like ripples in water as a pebble is dropped in to a pool. As a vibration signal is induced into the ground medium made up of innumerable adjacent particles within the rock and soils these particles are placed into random oscillatory motion. This random or elastic particle motion will eventually diminish through transition energy losses placing the particles back into their initial rest positions. Elastic ground particle motion of this type is generally classified into two major categories.

1. Surface Waves
2. Body Waves

Surface waves are elastic vibrations that are transmitted through the geology at the earths surface. Surface waves are further classified into these types of vibrations.

- Vertical and Horizontal Shear Waves - Back and forth motion
- Rayliegh Waves - Rotational motion
- P and S Waves – Compressional and shearing motion

Body waves are transmitted deep into the earth's crust and are returned back to the surface through a phenomenon called Refraction or Reflection. These reflected signals effectively change the characteristics of the surface wave.

The resulting characteristics of this ground vibration signal are mainly controlled by the energy of the source, the geology and the timing between blastholes. The measure and study of these vibrations is called seismology. Blasting seismology has become an important part of the explosives industry as more and more, the use of explosives must be conducted in populated areas. The units of measure commonly used to quantify the characteristics of the vibration signal are:

- Displacement – The actual distance the particle is moved when set in motion. This parameter is not usually used as the sole measure of a ground vibrations potential to cause structural damage. This distance is typically measured in thousandths of an inch.

- Velocity – This is the speed at which the particle is moving relative to its steady state or rest position. This parameter is measured in inches per second in three mutually perpendicular directions.
    1. Transverse - Horizontal motion at right angles to the blast.
    2. Vertical - Up and down motion.
    3. Longitudinal or Radial – Horizontal motion in the axis between the blast and recording location.

  The PPV (Peak Particle Velocity) is the maximum of the three above axis of particle motion. Most seismographs are designed to record this parameter of ground motion in real time. This time history information can then be processed to determine many other complex wave parameters.
- Acceleration – The rate in which the particle velocity of a complex wave changes.
- Frequency – The measure of the number of particle oscillations per second. The relationship of this parameter and particle velocity is the single most significant parameter to be considered when assessing the damage potential of blast induced ground vibrations.

Extensive research has been conducted throughout the last 40 years by the USBM (United States Bureau of Mines), universities and other private groups. This research has led to the development of acceptable vibration standards, vibration damage criteria, seismographs and techniques to predict and control blast vibrations.

The most widely accepted vibration standard to date is USBM RI 8507, titled, "Structure Response and Damage Produced by Ground Vibration from Surface Mine Blasting". This document provides data to substantiate the following conclusions:

1. Particle velocity is the single best ground motion descriptor and the most practical method for regulating damage potential for a class of structures with well defined vibration response characteristics.
2. Damage potentials for low-frequency blasts (<40 Hz.) are considerably higher than those for high frequency blasts (>40 Hz.), with the latter often produced by close-in construction and excavation blasts.
3. Home construction is another factor in the minimum expected vibration levels. Gypsum board (drywall) walls are more damage resistant than older, plaster on lathe constructed walls.
4. Practical safe criteria for blasts that generate low frequency vibrations are 0.75 inches per second for modern gypsum board homes and 0.50

inches per second for plaster on lathe interiors. For frequencies above 40 hertz, a safe particle velocity maximum of 2.0 inches per second is recommended for all homes.

5. Homes eventually crack because of a number of environmental stresses, including humidity, settlement, temperature changes, hydrostatic soil pressures, wind and even water absorption from tree roots. Consequently, there may be no absolute minimum vibration damage threshold when the vibration from any source could in some cases precipitate a crack about to occur.
6. The chance of damage from a blast generating peak particle velocities less than 0.50 inches per second is not only small (less than 5% for worst cases) but decreases more rapidly than the mean prediction for the entire range of vibration levels.
7. Human reactions to blasting can be the limiting factor. Vibration levels can be felt that are far below the levels to produce damage. Human reaction to blasting is dependent on vibration duration as well as amplitude.

Blast induced ground vibration is an impact from the use of explosives that has historically been an extremely difficult problem to effectively mitigate. There are many variables and site constants involved in the equation that when combined, result in the formation of a complex vibration waveform generated by the confined detonation of an explosive charge. The application of proper field controls during all steps of the drilling and blasting operation will help to minimize the adverse impacts of ground vibrations, providing a well designed blast plan has been engineered. This design would consider the proper hole diameter and pattern that would reflect the efficient utilization and distribution the explosives energy loaded into the blast hole. It would also provide for the appropriate amount of time between adjacent holes in a blast to provide the explosive the optimum level of energy confinement. After the blast has been properly designed, the parameters that have the greatest effect on the composition of the ground vibration waveform are:

- Geology between the blast site and the monitoring location
- Accurate timing between blast holes in a detonation sequence

Research developed by the USBM (RI 8507), universities, and others over the last 15 years in the blasting industry has concluded that a residential structure's level of response to a blast induced ground vibration is dependent on both the peak particle velocity and the frequency content of the waveform. The frequency is the number of oscillations that the ground particles vibrate per second as a blast vibration wave passes by the structure's location.

Seismic analysis of blast induced ground vibrations recorded adjacent to above ground structures indicates that most of the vibration energy of large scale blast generating PPV's greater than 0.05 inches per second is within the frequency band from 4 – 40 hertz. This same research has also shown that the resonant frequencies of typical residential homes are also from 4 – 18 hertz.

Above ground structures will resonate much like a tuning fork whenever they are excited by a vibration containing adequate energy matching the fundamental frequency of the structure. The value of this frequency is mainly dependent upon the mass, height and stiffness of the structure. Studies have shown that the actual structural response of the home can be greater than the ground vibrations due to amplification of the signal at its natural or resonant frequency. Likewise, if there is little or no energy at the resonant frequency of the structure, the structural response to the vibration will be negligible.

Further studies have also shown that there are direct relationships between the firing times of blast holes in a detonation sequence and the frequency composition of the ground vibration recorded at a particular structure in question. These studies have also concurred that a total blast sequence is simply defined as a series of single hole detonations that are separated by a given amount of time (Δt). It is the relationship between this Δt and the geology of the site that has the most effect on the amplitude and frequency composition of the ground vibration wave. The geology is generally the constant in the equation but it will change as the blasting operations move throughout the mine or quarry.

This relationship between timing and geology has led to the development of several sophisticated computer programs to predict and modify ground vibrations. These programs will process the recorded ground vibration signal induced during the detonation of a single hole blast at a given production blast location. The processing of this information through thousands of mathematical iterations yields a synthetic waveform. The computer model determines its amplitude and frequency composition for any given Δt between adjacent holes in a row and Δt between consecutive rows in a blast. The user then chooses the appropriate timing configuration that will yield vibrations that will not cause the structure to resonate.

This type of ground vibration modeling and prediction has until the recent introduction of electronic detonators, been only marginally successful. The inherent scatter in pyrotechnic detonators typically results in actual firing times of the blasting caps at times up to ± 10 percent of their nominal times. ie. a 100 ms detonator could fire at times from 90 to 110 ms. Inaccuracies of this magnitude are in most cases more than enough to negate the desired resulting effects the vibration modeling predictions and in many cases exacerbate the vibration problem.

The rock or burden response of the blast and the post blast muckpile are also dependent on the timing sequence of the blast. Too little time between holes or rows will result in a stacked muckpile that is very difficult for front loader to efficiently excavate. Too much time between holes or rows can result in unsafe blasts creating excessive air blast levels and flyrock. The optimum timing sequence that will mitigate the vibration impacts while simultaneously yielding the best blast performance is typically not achievable using the pyrotechnic delay times currently available in the blasting industry. Many times the optimum delay intervals are not achievable using the standard electric or non-electric (Nonel) factory defined intervals. Only the electronic programmable detonator will offer the exact detonation times these techniques demand.

The continued acceptance and use of electronic detonators will definitely result in improved techniques to modify the characteristics of blast induced ground vibrations.