

**Tight Construction Blasting:  
Ground Vibration Basics, Monitoring, and Prediction**  
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## **Introduction**

This is the first white paper in a series that is being prepared for close-in or tight blasting situations. These papers are basic and should be used as an introduction to blasting in municipal environments and other locations where close-in blasting is needed for rock excavation.

Effective blast design and optimization requires that a multitude of variables be choreographed into a single event. These variables include but are not limited to safety, borehole diameter, borehole depth, stiffness ratio, stemming height, stemming type, burden, spacing, subdrill, explosive type, explosive energy, explosive quantity, initiations systems, delay pattern, and the geology must be taken into account.

In close-in or tight construction blasting (1 foot to 20 feet), there is less margin for error because of the proximity of structures affected by flyrock and vibration effects.

There has been considerable study from the US Bureau of Mines and other government agencies on vibration and airblast effects from surface mining operations. But, there has been little research conducted on construction blasting and even less on the effects of close-in blasting. Due to this, the current municipal regulations do not reflect the type of blasting and blasting effects generated by tight blasting. These regulations are extremely conservative and becoming more so on a daily basis.

The current trend for engineers writing construction specifications is that if a 2-inches/second limit is good, a lower limit must be much better. They do not take into account the different type of blast geometry, explosive energy, vibration wave frequencies, building construction, or geology encountered.

Blasting is an engineering science, but since it is not an exact science, it is also an art. In construction blasting, especially tight blasting, this is even truer.

Anybody with an engineering or geologic background through either education or experience can read basic handbooks and understand the concepts and methods of blasting, but even the most educated will not truly understand or be able to do blast design, specification writing, monitoring in tight blasting situations without actual hands-on experience.

Sound blast designs are based on the following 4 factors:

1. Explosive Energy Confinement.
2. Explosive Energy Distribution.
3. Explosive Energy Level.
4. Explosives Application Experience.

Explosive energy confinement, distribution, and level can be calculated using basic explosive engineering formulas found in most handbooks. Explosives Application Experience is developed over time using different techniques and products in different types of applications and geologies.

The following document has been prepared using sound explosives engineering principles and the extensive experience of the author gathered during tight construction blasting projects, regular construction blasting, quarry blasting, and mining operations around the world.

This is a basic primer for the explosives engineer and blasters who have to perform blasting operations in tight quarters and municipalities.

### **Blast induced Ground Vibration**

In a simplified version of what happens when explosives are detonated in a blasthole, the chemical reaction of the explosives produces a high pressure, high temperature gas. This gas pressure (**detonation pressure**) crushes the rock adjacent to the blasthole. The detonation pressure decays or dissipates quickly. The second phase, which immediately follows or is in conjunction with detonation phase, is the shock and stress wave propagation phase. When the wave front moves forward, it will encounter discontinuities and/or interfaces. At these points, some energy is transferred across and some is reflected back.

During and after the stress wave propagation, high pressure, high temperature gases extend radial cracks and any discontinuity, fracture, or joint. The explosive energy will always take the path of least resistance. Once the blasted rock is separated from the bedrock, no further fracturing occurs because the gas pressure escapes. This entire process occurs within a few milliseconds from detonation of the explosives.

In basic terms, the energy not utilized in the breakage process is wasted energy. This energy is dissipated in the form of vibration, airblast, and watershock (charges in open water).

Vibration is a wave motion created from an energy source, in the case of rock blasting; the source is explosive energy and rock movement. Vibration wave motion is normal and

caused by many things including walking, running, cars, hammering, door slamming, and natural seismic events.

Primarily, blast induced ground vibrations are the result of the detonation pressure pushing the blasted rock away from the bedrock. This large force against the bedrock or unbroken portion causes the bedrock to vibrate. When the vibration is transmitted through the ground, this is called **propagation**. The **propagation velocity** is the speed at which the vibration waves travel. As vibration waves travel away from the energy source the vibration is reduced or decays, this is called **seismic attenuation**.

Properly designed blasts utilize the majority of explosive energy to break the rock. Poor designed blasts will have higher vibration levels due to wasted energy.

To understand blast-induced vibration, one must understand the following vibration components and terminology. A good example that is seen in many texts as an explanation of vibration is the following example.

The ground vibration caused from blasting is similar to the motion of a floating object placed in the water near the energy source. The distance between the wave crests that move the object is the **wavelength**. The speed at which they travel outward from the energy source and moves past the object is the **propagation velocity**, the **particle velocity** is the speed at which the object bops up and down, and the **frequency** is the number of times the object bops up and down in one second.

In blasting, ground particles oscillate in response to a vibration wave. This oscillation is measured in **particle velocity**. The maximum rate is the **Peak Particle Velocity (PPV)**. In blasting this is measured in inches per second or millimeters per second.

Velocity is a measure of the distance that could be traveled by particles in 1 second, measured in inches/sec (ips) (also known as speed in layman's terms). e.g. 60mph means something will travel 60 miles in 1 hr, 1 ips means a particle would move 1 inch in 1 second. The actual time that particles are moving is much less than 1 second, so even if we measure 2 ips, the ground may only actually move 0.2 inches if ground movement only occurred for one 10th of a second.

**Particle motion** is defined as ground particles oscillating in response to the arrival of the vibration wave. There are basically 2 types of vibration waves, **Body Waves** and **Surface Waves**.

**Peak Particle Velocity** is the maximum rate of particle movement; **displacement** is the distance the particle moves back and forth or the distance a particle or object moves from its position of rest. The change in displacement over a unit of distance is called **strain**.

Besides Peak Particle Velocity, the **frequency** is one of the most important factors controlling the response of structures. **Frequency** is the number of times the particles move back and forth in one second. This back and forth motion can also be referred to as **oscillations**. The number of oscillations/second or cycles/second that a particle makes under influence from the vibration wave is measured in **Hertz (Hz)**.

Frequency is dependent on site geology, distance to the blast, and delay sequencing (hole firing time).

The nature of the effect of frequency allows tight blasting without damage and also can allow higher peak particle velocities. Within 1-2 meters or 3 to 7 feet, blast frequencies can be many thousands of hertz. Although, they attenuate or decay quickly, the frequency can still be extremely high at a monitoring point under 20 feet. These frequencies can be so high that normal equipment cannot measure the level.

Structural dynamics research has shown the importance of vibration wave frequency in tight blasting situations. In many cases, blast limits and specifications are based on blasting situations in mining and quarrying. Frequency, although looked at in regards to standard blasting limits is hardly ever taken into account when designing specifications for tight blasting.

When structures are excited by blast vibrations, that may be equal in all variables, except frequency, the structure in question will respond much differently to a ground motion with a principal frequency of 20 hertz as opposed to a ground motion with a principle frequency of 150 hertz.

To complete tight construction blasting projects in a cost effective, timely manner, and with minimal impact on surrounding structures, it is imperative that the explosives engineer understands the importance of frequency in specification writing, blast design, and interpretation of results.

Also, it is important for the explosives engineer to have a firm grasp of other methods to define vibration wave peak. During the monitoring of a blasting project, the term **acceleration** maybe used to define the vibration wave peak or intensity. Acceleration should always be examined in terms

of the principal frequency and should not be used as a stand-alone limit.

**Acceleration (a)** is defined as the velocity per unit of time. As an example would be the car commercial that states "0-60 in 10 seconds". The car is accelerating to 60 miles/hour in 10 seconds, which means there is a speed (velocity) that is calculated over time. The acceleration would be 6 mph/second.

The combination of vibration wave peak particle velocity (the peak speed the particle moves from rest to highest displacement and back down like the bobbing cork example stated earlier), and the frequency (number of movements in 1 second) are used to calculate acceleration. The gravitational acceleration on the earth's surface (constant of 386.4 inches/second<sup>2</sup> = 1 gravity (g)) is used to convert the acceleration measurement (which is measured in inches/second<sup>2</sup>) to gravity.

The formula used is for approximate maximum acceleration is:

$$Accel. = \frac{2 * \pi * V * f}{386.4}$$

Where: Units of acceleration = gravity, V= PPV (ips), f = frequency (Hz).

We can calculate acceleration or measure it with the seismograph. When acceleration is calculated instead of measured, the number is usually much lower than the actual result because the vibration wave is not a true sinusoidal curve. This is also the reason when using acceleration and frequency to convert to peak particle velocity in inches/second that it too is an approximation. But, this can give us a good approximation of what's happening.

In close-in blasting situations, high accelerations can make the perceived vibration seem more intense and can also make the seismic data unreliable.

## **Seismographs**

To measure blast vibration, we use instruments called seismographs. The geophone is the part of the instrument that contains sensors. The geophone must be firmly attached to the material that is being monitored. If the geophone moves more than the material, it has **decoupled**. When monitoring close-in construction, this can readily occur especially if vibration wave acceleration is exceeding 1 g. When acceleration exceeds 1 g, it is much more likely that the seismograph sensor or geophone will experience decoupling.

As an example, if a board is sitting on top of a table, and the table experiences some type of force, the board will move much more than the table. In this example, the board is equivalent to the geophone. When a blast occurs, the rock is barely shaking or vibrating, but the geophone moves. The vibrations being recorded are actually the geophone moving, not what the rock is experiencing.

There are other problems that may occur to seismographs when used for close-in monitoring. These include exceeding the operational limits of the transducer and/or aliasing.

Inside of the geophone are the instruments that measure the vibration. In most commercial seismographs, these instruments are called **Seismic Velocity Transducers**. A coil moving through a magnetic field measures the output of the transducer.

In cases where the vibration frequency is high (over 250 Hz), the peak particle velocity approaches four inches/second, acceleration is over 1 g, or the geophone is placed in an area that will experience a multitude of different wave types at the same time, transducer decoupling may occur. This happens when the coil inside of the magnetic field moves enough to disrupt the magnetic field. This is exceeding the operational limits of the transducers.

Acceleration transducers or accelerometer seismograph units can be employed for close-in monitoring in the near field, but do not function well for midfield or far field monitoring. Again, if setup in the wrong location, it too can generate anomalous readings.

Using the same table and board example: If someone pounds on the table, the board will jump or bounce up. If a bag of sand is placed on the board, it will be held down. Although, a large enough force applied to the table will still move the board and sand bag. Because the instruments are being set up so close to the blast, no amount of cover will keep the geophone from moving more than the rock. Also, as first example demonstrates, even if the geophone is not decoupling, the transducer can be stressed beyond the operational limits.

**Aliasing** is a phenomenon, which can occur whenever a signal is not sampled at greater than twice the maximum frequency of the signal. This causes high frequency signals to appear at low frequencies. Also, to measure the amplitude correctly in high frequency situations, the sample rate must be at least 4-5 times of the actual frequency being monitored.

Frequencies in the extreme near field can be as high as 6000 Hz. Although, this signal **attenuates** quickly, it can still be many hundreds of hertz within 20 feet of a blast. This will exceed most commercial blasting seismograph operational limits and will generate erroneous data.

In other words, if an attempt is made to use normal commercial seismographs in the extreme near field to monitor blasting, the operational limits of the seismic transducers or data collectors will be exceeded in the particle velocity and frequency measurements, which will generate incorrect data.

### **Vibration Waves**

To understand vibration control in tight blasting, the explosives engineer must understand vibration wave construction and phenomenon.

Blast induced vibration waves can be divided into three main categories: compressive, shear, and surface. To measure the motions, three perpendicular components of vibration motion must be measured. They are as follows:

#### Ground vibration direction

1. **Transverse**- horizontal motion at right angles to the blast.
2. **Vertical** - Up and down movement
3. **Longitudinal (Radial)**\_- Horizontal movement along a line between the recorder and the blast.

The three main vibration wave types can be divided into **body waves** and **surface waves**.

Body waves propagate through the body of the rock or soil. One type of body wave is known as **P-Waves** (Compression and Tension Waves). P-Waves are Push/Pull waves and they are the compression/dilatation in the direction of wave travel. They travel in the following mediums: solids, liquid, gas. The compression creates a change in volume of the medium. An example of these types of waves occurs when a rope or string is stretched and vibrates.

The other type of body wave is the **S-Wave**. This is a transverse wave that moves at right angles to the direction of wave travel. These waves can only travel in a solid medium. S-Waves create a change in shape of the medium. An example would be flexing a rope. The rope moves up and down, but the wave travels to the other end.

At small distances as those seen in close-in blasting, blasts produce predominantly body waves. These body waves propagate outward somewhat spherically until they contact

any boundary. These boundaries can include another layer of rock, free face, fracture, joint, surface, or soil. When body waves arrive at these intersections, surface and shear waves are produced.

**Surface Waves** travel along the outer surface layer of rock. They do not penetrate into the rock mass. The wave motion of surface waves decreases with depth. 1 wavelength in depth is equal to zero motion or no surface wave.

Surface waves are larger than body waves but travel slower (Frequency). These are the waves, which cause most of the vibration problems and complaints. These waves are the large energy carriers and produce the largest motions. There are two basic types of surface waves, the **Love Wave** and the **Rayleigh Wave**. Love Waves are transverse waves that propagate in a surface layer on top of another medium (Soil overlying rock). Rayleigh waves travel in the free surface and the particle motion is elliptical.

When blasting in the extreme near field (under 20 feet) without a soil layer, these surface waves are almost non-existent. For the development of regulations, the studies and research performed mostly involved the measurement of surface waves at large distances. In tight blasting situations, the body waves are the dominant waves and create surface waves when interacting with structures. Normally when body waves interact with a free surface, the peak particle velocity is doubled.

If a seismograph is setup in an incorrect location such as near structures, etc, this doubling phenomenon will cause erroneous data.

Transmission and reflection of vibration waves also affect the peak particle velocities. In the case of two equal compression waves colliding, the stresses will add and double. Once they pass, they will resume their initial form and continue. In conditions where two opposite waves (compression and tension) collide, the stresses will cancel one another and then continue on and resume their initial form.

If a seismograph is setup in an area where there are a multitude of surfaces and structures, the interaction of the vibration waves with each other, surfaces, and structures may cause the seismograph readings to be erroneous and not representative of the actual peak particle velocities affecting the structure.

Seismographs should be setup outside of the structure of concern. If seismographs must be setup inside or on the structure of concern, an analysis should be completed that



indicates the damping and/or the amplification effect of the structure.

When monitoring inside of a structure or extremely close to the blast, an array of seismographs should be used in various locations to insure that the proper readings are being recorded.

Using vibration prediction formulas, and information from the seismograph array, a good approximation of the peak particle velocity can be calculated at the point or seismograph in question.

Many regulations and studies incorporate the use of **scaled distance** for some basic vibration prediction and blast design starting points.

### **Scaled Distance**

**Scaled Distance (SD)** is a scaling factor that relates similar blast effects from various charge weights of the same explosive at various distances. Scaled distance is calculated by dividing the distance to the structure of concern by a fractional power of the weight of the explosive material.

There are two excepted scaled distance formulas used in blasting, square root scaling and cube root scaling.

Square root scaling is the general formula used in most regulations and general blasting situations, where the charge can be considered linear. Cube root scaling is used for blasting in the extreme near field where the charge can be considered a point charge or in explosions involving very large quantities, such as those created by nuclear explosions. Ambraseys and Hendron first suggested cube root scaling for use in prediction of blast vibrations in the year 1968.

### **Square Root Scaling**

Many times when construction-blasting specifications are encountered, designing to a certain square root scaled distance factor is required. This is useful as a beginning estimate for vibration control and provides a conservative and safe charge weight for the test blast program. Since explosives confinement is not taken into consideration, there can and usually is a large variation in results, especially in tight blasting situations. It should be noted that small charges generate vibrations with higher frequencies and smaller displacements.

A 1.5-lbs. (.68 kg) charge of explosive will USUALLY generate more vibration than 3 - 1/2-lbs. (.2 kg) charges even when detonated at the same time.

#### **Square Root Scaled Distance Formula**

$$\text{Scaled Distance (SD)} = \frac{\text{Distance Structure}}{\text{Weight}^{0.5}}$$

Or,

$$\text{Weight} = (D/SD)^2$$

#### **Cube Root Scaling**

Cube root scaling should be used for vibration prediction in the extreme near field (under 20 feet) in construction blasting. Cube root scaling can also be used as the basis for the prediction of frequency, but that will not be discussed here.

#### **Cube Root Scaled Distance Formula**

$$\text{Scaled Distance (SD)} = \frac{\text{Distance Structure}}{\text{Weight}^{0.33}}$$

Or,

$$\text{Weight} = (D/SD)^3$$

#### **Delay Sequencing**

Blasting regulations usually state that only a certain amount of explosives may be detonated per delay, this has come to be known as the 8 millisecond delay window or 8 ms window. What this means is that amount of explosives being detonated at a given time not overlap with other blastholes being detonated within 8 ms. Years ago, researchers realized that charges needed to be separated to achieve optimum fragmentation and vibration response. At the time, the explosives initiation systems available could provide a separation of at least 8 ms on paper, so, 8 ms was recommended as the minimum time needed for separation of charges.

Separation of charges is extremely geology dependent. With the advent of modern electronic microsecond accurate initiation systems, this author believes that this be viewed on a case-by-case basis after analysis of the area to be blasted is completed.

## Vibration Prediction

Basic prediction of peak particle velocity can be achieved using Oriard's formula, which follows:

$$PPV = K \times (D/W^{1/2})^{-1.6} = (SD)^{-1.6} \times K$$

- PPV = Peak Particle Velocity in inches/second (ips)
- SD = Scaled Distance
- $^{-1.6}$  = to the -1.6 power
- K = Confinement Factor

Lower Bound: 20

Average: 150

Upper bound: 242

Highly confined: 605,

To calculate the "K" factor, use the following formula:

$$K = PPV / (D/W^{1/2})^{-1.6}$$

Example:

PPV = 1.4 ips, lbs. = 7, D = 20'

$K = 1.4 / (20/7^{1/2})^{-1.6}$

K = 35.62

1. Calculate Scaled Distance = SD = Distance/Weight<sup>1/2</sup>
2. Calculate SD to the -1.6 power
3. Multiply by the "K" factor. - Choose the "K" factor or calculate from previous blasts.
4. K x SD<sup>-1.6</sup> equal to your predicted PPV.
5. K factor has huge significance.
6. If this formula is used well, it can be accurate. This formula is used in regression curves, but "K" factor and power are calculated from the data.

**Peak Particle Velocity Prediction Table for various SD & K.**  
Table: SD = Scaled Distance, K = confinement factor

	<u>Lower Bound</u>		<u>Average</u>		<u>Upper Bound</u>		
<b>SD/K</b>	<b>20</b>	<b>75</b>	<b>150</b>	<b>160</b>	<b>205</b>	<b>242</b>	<b>605</b>
10	0.50	1.88	3.77	4.02	5.15	6.08	15.20
<b>15</b>	<b>0.26</b>	<b>0.98</b>	<b>1.97</b>	<b>2.10</b>	<b>2.69</b>	<b>3.18</b>	<b>7.94</b>
20	0.17	0.62	1.24	1.33	1.70	2.01	5.01
<b>25</b>	<b>0.12</b>	<b>0.43</b>	<b>0.87</b>	<b>0.93</b>	<b>1.19</b>	<b>1.40</b>	<b>3.51</b>
30	0.09	0.32	0.65	0.69	0.89	1.05	2.62
<b>35</b>	<b>0.07</b>	<b>0.25</b>	<b>0.51</b>	<b>0.54</b>	<b>0.69</b>	<b>0.82</b>	<b>2.05</b>
40	0.05	0.21	0.41	0.44	0.56	0.66	1.65
<b>45</b>	<b>0.05</b>	<b>0.17</b>	<b>0.34</b>	<b>0.36</b>	<b>0.46</b>	<b>0.55</b>	<b>1.37</b>
50	0.04	0.14	0.29	0.31	0.39	0.46	1.16
<b>55</b>	<b>0.03</b>	<b>0.12</b>	<b>0.25</b>	<b>0.26</b>	<b>0.34</b>	<b>0.40</b>	<b>0.99</b>
60	0.03	0.11	0.21	0.23	0.29	0.35	0.86
<b>65</b>	<b>0.03</b>	<b>0.09</b>	<b>0.19</b>	<b>0.20</b>	<b>0.26</b>	<b>0.30</b>	<b>0.76</b>
70	0.02	0.08	0.17	0.18	0.23	0.27	0.68
<b>75</b>	<b>0.02</b>	<b>0.07</b>	<b>0.15</b>	<b>0.16</b>	<b>0.20</b>	<b>0.24</b>	<b>0.60</b>

#### **Vibration Prediction with Hendron's Formula & Cube Root Scaling**

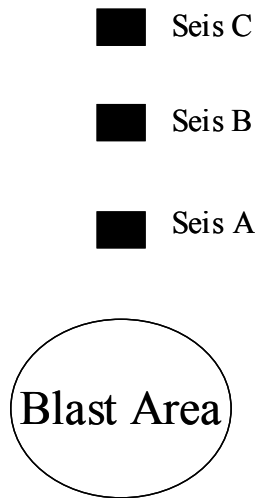
Using the formula:  $PPV = K \times (D/w^{.33})^{-1.6}$ , vibration for very close-in or tight blasts can be predicted in the same format as using Oriard's formula except substituting cube root scaled distance factor for the square root scaled distance factor.

To predict vibration and check the output information recorded by seismographs in a seismograph array, both formulas can be used to determine the correctness of data.

When setting up a seismograph array, seismographs are setup at the closest point of concern to the blast. In tight blasting situations, as explained earlier, this can lead to erroneous data. Special units can be purchased or built specifically for this type of situation, but this can be costly and time consuming.

To validate data, other seismographs should be setup in-line and behind the closest unit.

The following diagram shows a typical seismograph array:



Data:

4 lbs/delay

Seismograph A = 15 feet from blast, PPV = 1.40 ips

Seismograph B = 35 feet from blast, PPV = 0.53 lps

Seismograph C = 50 feet from blast, PPV = 0.30 ips

Extrapolation of the data follows:

First, calculate the K factor for Seismographs B & C.

Seis B:  $K = 0.53 / (35/4^{.5})^{-1.6} = 51.66$ , Seis C:  $K = 0.30 / (50/4^{.5})^{-1.6} = 51.73$

Second, take the average of the two K factors =  $(51.66 + 51.73) / 2 = 51.69 = 51.70$

Third, calculate the expected Peak Particle Velocity for seismograph A and compare the data. Because seismograph A is under 20 feet, we can assume the blastholes will act as a point charge and use Hendron's formula, which uses cube root scaling.

Use the average K factor developed from the array and replace in Hendron's formula:

$PPV = K \times (D/W^{.33})^{-1.6} = 51.70 \times (15/4^{.33})^{-1.6} = 1.41$   
**ips**

The actual reading taken from the seismograph was 1.40 ips. The calculated reading (1.41 ips) and the seismograph "A" reading are basically equal and it can be assumed the seismograph is accurate.

If the geophone of seismograph "A" has decoupled or the readings are above the operational limits of the unit, this technique can be used to give an estimate of probable peak particle velocity at seismograph "A".

This technique should only be used after thorough research and investigation into the response and accuracy of the seismograph array.

Another technique used for vibration prediction is the use of a **regression analysis**.

### **Regression Analysis**

Regression Analysis is the process of estimating peak particle velocity (dependent variable) statistically from the independent variables of explosive weight/delay and distance to the structure of concern (scaled distance).

Peak particle velocities tend to decrease with the increase of scaled distance. This means that by plotting the data on a log-log graph will give the appearance of a linear relationship. From this data, an equation for the best fit or mean can be developed as:

$$PV = K \times (SD)^s$$

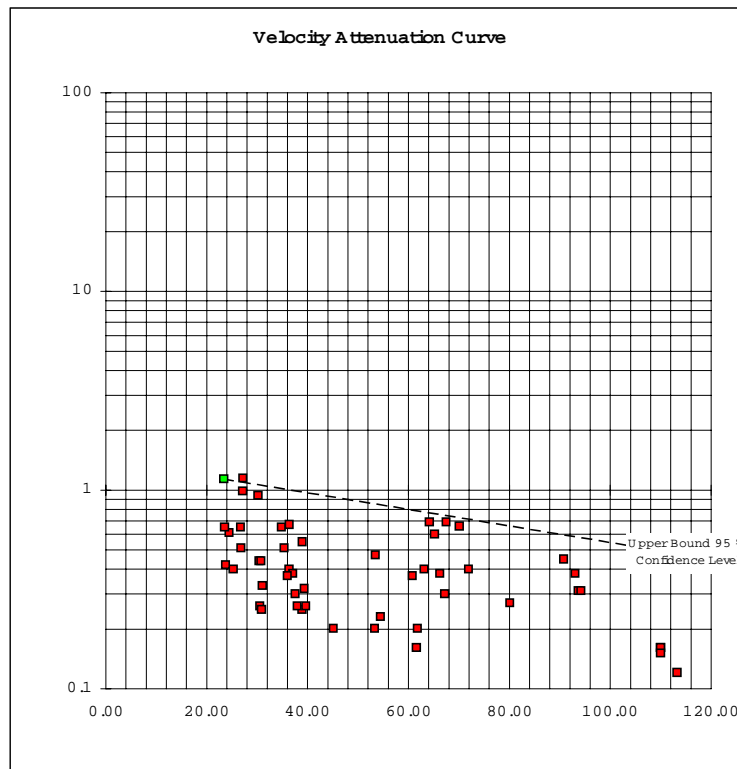
Where PV = the particle velocity and K is the y-intercept, it represents the value of the line when it intercepts the particle velocity axis at a scaled distance of 1. "S" is called the slope. The slope represents the decrease in particle velocity as the scaled distance increases.

From the standard deviation of the data, confidence intervals can be determined, which are based on an amount of explosives/delay that can be detonated at a certain distance. For example, a confidence range of 50% means that 50% of the data will fall below the 50% confidence line. If the analysis generates data that is interpreted based on a vibration limit of 1.0 inch/second, that 8 lbs/delay of explosives can be detonated at 20 feet and statistically, 50% of the peak particle velocities will be below 1 inch/second.

Normally, in blasting, a 95% confidence line is calculated. To develop a good analysis, a minimum of 30 - 35 data sets need to be analyzed. If done properly and enough seismographs are used, this can be accomplished and begun in the test blast program.

Regression analysis should be continued throughout the project and blast design should be adjusted accordingly.

A typical regression analysis graph using square root scaled distances follows as an example.



Utilizing the techniques of regression analysis and the vibration prediction formulas, blasts can be optimized and designed with confidence for close-in or tight blasting. The added benefit of high frequencies helps to reduce the potential of vibration effects and damage.

#### **DEFINITIONS OF VIBRATION EFFECTS AND DAMAGE**

All houses crack from environmental forces. These forces include temperature change, humidity change, and settling. Other forces interact with structures and also cause damage. It is extremely difficult to distinguish between blast-induced damage and normal aging effects.

1. Threshold effects- refers to hairline cracks that may or may not be seen by the naked eye (75 microns or less). Threshold effects do not damage the structural integrity of the structure.
2. Minor Damage- Cracks that are visible to the naked eye but do not effect the structural integrity of the structure. May or may not be repaired. It usually depends on the aesthetic appearance. Quarry and construction blasting with PPV as low as 2-3 ips (50.8 mm/s - 76 mm/s) has been known to damage houses, but in a

normal house, it usually takes between 5.5-6.5 ips (137 mm/s - 165 mm/s) or higher.

3. Major Damage- Damage from blasting usually does not reach these levels. This type of damage is associated with earthquake levels of vibration. Usually involves structural damage.

Various government agencies have based regulations and blast limits on results of studies of large scale blasting operations.

The types of blast designs, explosives, and blast pattern geometry are much different than those encountered in tight or close-in construction blasting.

Normally, in tight blasting situations, small diameter explosives (2 inch or less) are used in short blast holes (12 feet or less). Whereas, in large-scale long-term blasting operations, 8-inch diameter charges (or greater) over 40 feet deep are employed. These large charges create large surface vibration waves that are large energy carriers and have low frequencies.

In tight blasting situations, it is not uncommon to have vibration frequencies as high as 1000 hertz at 15 feet and many thousands within 5 feet. Also, the propagation velocity of the wave is so fast at these short distances, the peak particle velocity only lasts for a short duration. With these high velocities and frequencies, structure damage potential is low, especially with concrete and brick structures.

Below are common **residential** criteria developed by various regulatory agencies, they should not be applied to close-in or tight blasting situations.



### **Range of Common Residential Criteria and Effects**

0.5 ips 12.5 mm/s	Bureau of Mines recommended guideline to prevent threshold damage in plaster-on-lath construction near long-term, large-scale surface mines with large scale blasting operations. (RI 8507)
0.75 ips 19.1 mm/s	Bureau of mines recommended guideline to prevent threshold damage in sheetrock construction near long-term, large-scale surface mines with large scale blasting operations. (RI 8507)
1.0ips 25.4 mm/s	OSM regulatory limits for residences near long-term, large-scale surface mines with large scale blasting operations at distances of 300 - 5000 feet (9840 m - 16,400 meters).
2.0ips 50.8 mm/s	Widely accepted limits for residences near construction blasting and quarry blasting. (BuMin Bull 656, RI 8507, various codes, specifications, and regulations). Also allowed by OSM for frequencies above 30 Hz.
5.4 ips 137 mm/s	Threshold effects to the average house subjected to quarry blasting vibrations. (BuMin Bull 656)
9 ips 229 mm/s	About 90% probability of Threshold damage from construction or quarry blasting vibrations. (BuMin Bull 656)
20 ips 508 mm/s	For close-in construction blasting, minor damage to nearly all houses, structural damage to some. For low-frequency vibrations, structural damage to most houses.
<b>NOTE</b>	<b>THE ABOVE CRITERIA APPLY ONLY TO RESIDENCES, NOT TO ANY OTHER FACILITIES OR MATERIALS</b>

**ISEE BLASTERS HANDBOOK- 17<sup>TH</sup> EDITION**

Below are recommendations based on the author's experience for a starting point to develop acceptable levels or vibration limits for close-in blasting (under 20 feet).

### **Safe and Conservative Blasting Limits**

<b>Peak Particle Velocity</b>	<b>Structure</b>
2.0 ips - 51 mm/s	Residential Homes with plaster on lath construction
2.5 ips - 64 mm/s	Residential Homes with sheetrock construction
3.0 ips - 76 mm/s	Commercial Structures/buildings
3.0 ips - 76 mm/s	Wooden Bridge
5.0 ips - 127 mm/s	Well-cured concrete- can vary up to 375ips
5.0 ips - 127 mm/s	Steel/reinforced concrete bridge
5.0 ips - 127 mm/s	Buried pipelines- blast out of fracture zone.
15.0 ips - 381 mm/s	Cased drill holes

Tight blasting around reinforced concrete structures can be looked at as though the concrete is manmade rock.

Lewis Oriard has done considerable work in researching effects on these structures. This author has used his basic recommendations many times without a problem. The following is referenced in the International Society of Explosives Engineers Blasters handbook and books by Oriard (see bibliography).

When blasting outside the boundaries of concrete the results are variable and are dependent on how the concrete was poured, type of reinforcement, and raw materials used.

Tests have shown concrete not to generate cracks until 375 ips was reached and craters not forming until 600 ips. The author does not recommend using these as limits, but it shows the variability of concrete.

In 1976, the Tennessee Valley Authority (TVA) developed limits based on Oriard's research and investigation. These are still conservative and can be applied to concrete footing, walls, dams, bridges, etc.

The limits are based on concrete age and distance from the blast. A distance factor (DF) was developed to multiply by acceptable peak particle velocity limits based on the age of the concrete in hours and days.

The following charts show the concrete age, allowable peak particle velocity, and distance factor. These are used to generate allowable conservative limits for blasting.

Concrete Age	Allowable PPV- IPS (mm/s) x Distance Factor (DF)
0 - 4 hours	4 ips (102 mm/s) x DF
4 hrs. - 1 day	6 ips (152 mm/s) x DF
1 - 3 days	9 ips (229 mm/s) x DF
3 - 7 days	12 ips (305 mm/s) x DF
7 - 10 days	15 ips (381 mm/s) x DF
10 days and up	20 ips (508 mm/s) x DF

#### Distance Factor (DF)

Distance = 0 - 50 ft (0 - 15 m)	DF = 1.0
Distance = 50 - 150 ft (15 - 46 m)	DF = 0.8
Distance = 150 - 250 ft (46 - 76 m)	DF = 0.7
Distance = >250 ft (76 m)	DF = 0.6

For example, if concrete is 1.5 days old and blasting is 15 feet away, the allowable peak particle velocity would be 9.0 ips.

Age: 1-3 days = 9 ips  
Distance 15 feet, DF = 1.0  
9.0 ips x 1.0 = 9.0 ips

If the structure is above ground (freestanding wall, etc), this limit can be divided in half for safety. Example: 9 ips ÷ 2 = 4.5 ips

As can be seen, residential and conventional limits should not be placed on tight or close-in blasting operations, especially on concrete reinforced structures.

Thorough research needs to be completed before any limits and specifications are written for the blasting operations. Too often, engineers are hired to write blasting specifications that do not have the appropriate experience to develop specifications that will allow safe and efficient blasting without undue limitations.

Many times blasting specifications are developed for public relations and public perception.

The following graph comes from a study completed by the US Bureau of Mines in the early 1980's. As can be seen, individuals are extremely sensitive to vibration. When most individuals experience blast-induced vibration, it seems to be much higher in intensity than actual.

### **BLASTING COMPLAINTS**

<b>Peak Particle Velocity- ips, mm/s</b>	<b>% of Complaints</b>
< 0.10, 2.54	1.0%
0.10, 2.54	1.5%
0.20, 5	5.0%
0.40, 10.2	10%
0.60, 15.2	15%
1.00, 25.4	20%
1.50, 38	40%
2.00, 50.8	50%
4.00, 101.6	70%

Regulations are in place to reduce complaints. As can be seen from the above information, damage normally will not occur in properly functioning and designed blasts.

Damage is normally caused by long duration vibration waves with high peak particle velocities and low frequencies. For example, an earthquake can have peak particle velocities of 30 ips or greater with frequencies below 1 hertz and last many seconds.

To a human, a blast vibration wave with a peak of 1.5 ips and a frequency of 40 Hz and duration of 0.5 seconds may feel just as intense.

## Summary

When writing specifications, constructing blast designs, and investigating blasting related complaints in close-in or tight blasting situations, it must be remembered that the regulations developed for blasting are usually not based on tight blasting situations.



Thorough and complete research and investigation needs to be started and kept on-going throughout the project duration to insure that blasting can be completed cost effectively and efficiently without causing damage to surrounding structures, equipment, personnel, and keeping neighbor and abutter complaints to a minimum.

The vibration frequency component is key in developing blast designs for tight blasting situations. If blasting limits are created that are different then current blasting regulations in-place in states and/or municipalities, then the limits should be based on a combination of frequency, peak particle velocity, and the type of structure affected by the blast induced vibration.

Monitoring tight blasting situations can be difficult. The proper equipment needs to be purchased or built specifically for these types of projects. This should be part of the blasting specification. The specification should also take into account monitoring location. If equipment cannot be obtained that can monitor the blast from the proper locations, specifications can be developed for monitoring from a farther location based on vibration wave attenuation.

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