

# Case Study

## Selection of Blasting Limits for Quarries and Civil Construction Projects

The selection of appropriate blasting vibration limits for civil construction projects and quarry operations has a major influence on the overall cost, duration, and environmental impact of a project. In some cases the application of an overly conservative limit may affect the financial viability of a project to a point where it may not even commence, despite it going through all the relevant planning approvals. Low vibration limits have resulted in explosive blasting being precluded from some major projects in favour of slower, more disruptive, mechanical methods such as ripping and hammering. This has prolonged the duration of the projects and extended the community's exposure to excavation noise and dust.

Due to the current growth and investment in infrastructure, a large amount of Australian Quarry and Construction blasting in recent years has been in Queensland. Blasting in Queensland is governed by various legislation, standards and guidelines, often referencing different limits.



*Image 1: Orica construction team, Advanced Vibration Management, Airport Link Project, Brisbane.*

While humans are good at detecting ground vibration at very low levels, laboratory research and field experience has shown that humans have difficulty in distinguishing between different magnitudes of vibration. Many people do not realise that everyday sources create similar, and often higher, vibration levels than those suggested in the relevant legislation and standards for blasting.

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Successful management of the environmental effects generated by blasting relies as much (if not more) on community relations as it does on complying with imposed limits. Experience has shown that many people are willing to tolerate short bursts of high vibration from blasting as long as they are made aware of when it is going to happen by suitable pre-blast warnings.

Given that humans are poor at distinguishing between different magnitudes of blast vibration, one could argue that the lowest overall environmental impact is achieved by accepting a higher vibration limit with a consequential reduction in project duration, associated drilling noise and number of blast events. A small portion of the hundreds of thousands of dollars that would be saved can be set aside for repair of any cosmetic damage claimed, although in most cases actual damage is unlikely at levels below 50mm/s.

This article discusses some of the vibration limits relevant to blasting, and looks to explore the effect that the application of a blanket low level vibration limit can have on the cost and efficiency of a project, and the resultant effect on the community. It also discusses the principles of frequency-based criteria, and explains why it is important to consider both frequency and amplitude when choosing blast vibration limits.

### Measuring Vibration from Blasting

Blast-induced ground vibration can be measured in three different ways; as acceleration, velocity and displacement.

**Acceleration** is a measure of how quickly the point of interest changes velocity over a set period of time. This is usually expressed in millimetres per second per second,  $\text{mm/s}^2$ , or as a multiple of gravitational acceleration ( $9.8\text{m/s}^2$ , or “g”). Acceleration on its own does not necessarily cause damage, but differential acceleration between objects or structures can create dynamic stresses and strains, causing damage.

**Velocity** is a measure of how far the point of interest moves in a set period of time; usually expressed in millimetres per second ( $\text{mm/s}$ ). Like acceleration, velocity on its own does not cause damage. A house, car or person can sustain high speeds without damage; we see this every time we fly in a passenger jet.

**Displacement** is the distance that the point of interest moves from a certain reference point. This is usually expressed in millimetres (mm). Displacement alone does not cause damage; a house on the back of truck can be moved kilometers without being damaged. It is differential displacement (strain) that ultimately causes damage.

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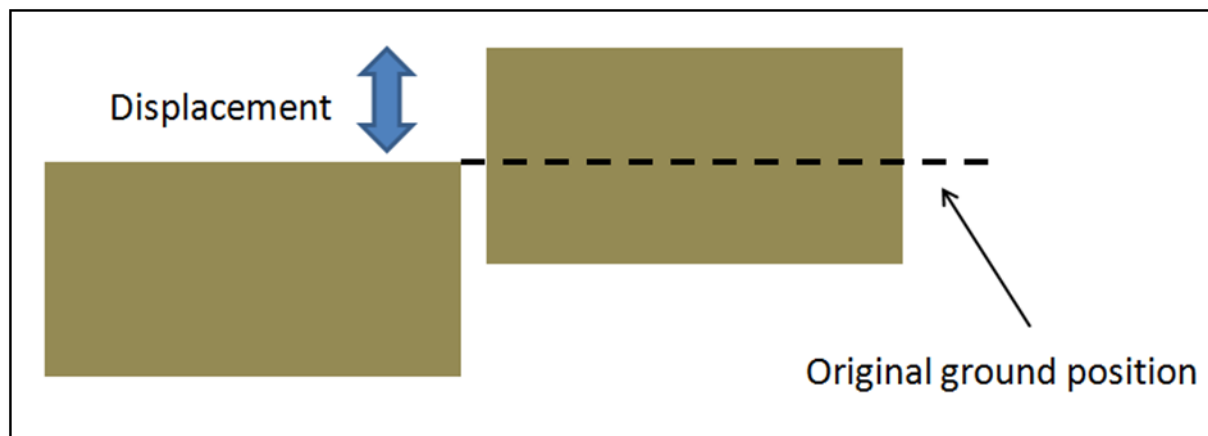


Figure 1: Graphical representation of displacement

The method used to measure ground vibration is dependent on the blasting application and the type of data that needs to be collected. Velocity is the most common method used to measure ground vibration. This is because it is relatively easy to measure, and it is referenced in most relevant legislation and standards. Velocity is measured with an instrument called a geophone.

Acceleration is a less common way of measuring ground vibration. This is because it is not referred to in many blasting standards. However, manufacturers of sensitive equipment such as computer hard drives sometimes provide maximum vibration limits in terms of acceleration, measured in “g”. Acceleration is also preferred to velocity when measuring vibration for research and scientific purposes, as the equipment used can detect vibrations over a wider range of frequencies than geophones.

### Understanding the Concept of Frequency

Using the analogy of sound, the concept of “frequency” in a blast waveform is the same as the “pitch” of a sound. Vibrations from a blast usually occur across a wide range of frequencies. Imagine a child sitting at a piano. When the child bashes keys up and down the whole keyboard, they create a wide range of frequencies that our ears detect as sound. While people are good at distinguishing and comparing the volume of pitch of different sounds, we are not as good at distinguishing the relative intensity and different frequencies of blasting vibrations.

When Orica analyses a blast waveform, Orica usually describes the “dominant” frequency. Using our piano analogy, the dominant frequency is the key that the child is striking the loudest. If the child is hitting all the keys at the same volume, the dominant frequency may not actually be that much louder than all the rest. The “dominant” frequency does not represent the full spectrum of frequencies, or tell us anything about all the other frequencies from the blast. It simply describes which frequency was louder than all the rest.



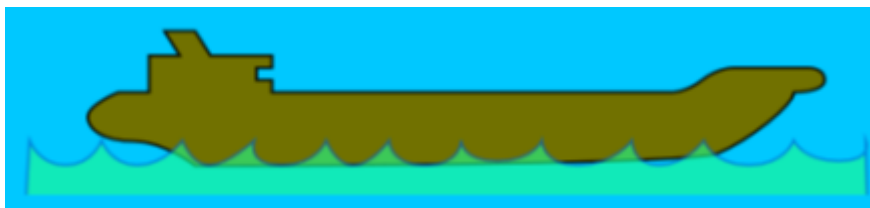
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Sounds or vibrations at low frequencies (from the bottom end of the piano keyboard) tend to carry further than those at high frequencies. Put another way, high frequencies tend to die out quickly. Using the sound analogy, if a rock band is playing next door, you can hear a wide range of frequencies – from the high notes of the lead guitar, all the way down to the low notes of the bass. However, if the band is a kilometre away, you only hear the lowest notes from the bass and the bass drum.

The same principle applies to blast vibrations – low frequencies carry further. Vibration measurements made closer to a blast will contain a wide range of frequencies compared to measurements made a long way away. Hence, measurements made close to a blast are likely to have a higher “dominant” frequency.

If a blast has a particularly low dominant frequency, it may be particularly noticeable to people and generate complaints. This is usually because the blast is “exciting” or “matching” the natural frequency of part of a structure (such as a floor or wall) that the people occupy. (Every building and part of a building has a natural frequency, and for the large elements of a building, the natural frequency is usually low). As an analogy, consider the ship in Figure 2 below:



*Figure 2: Choppy Waves - High Frequency*

This ship is large, and if disturbed it naturally rocks from side to side at a steady and fairly slow frequency – maybe one cycle every few seconds. The same principle applies to structures – if disturbed, they continue to “vibrate” at their natural frequency, although this is rarely noticeable to the people inside.

If the wind generates waves at a high frequency, as in Figure 2, the ship will remain relatively undisturbed. The frequency of the waves is well above the natural frequency of the ship.

In a similar scenario with the same ship, if the waves occur at low frequency, the boat will respond with much greater movement, as illustrated in Figure 3. The waves are now matching the natural frequency of the ship, and it rocks from side to side with much larger movements – and everybody onboard notices!

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*Figure 3: Rolling Swell - Low Frequency*

The same principle applies to blast vibrations. Low frequency vibrations are more likely to match the natural frequency of large structural elements in buildings, and create sustained vibration (resonance) that people notice, and this leads to complaints.

Like blasting, hydraulic rock hammers create a range of frequencies each time the hammer strikes the rock. However, the dominant frequency of the hammer's total vibration waveform is created by the repetitive action that occurs around once or twice per second. Thus, rock hammers have a relatively low dominant frequency, and this, combined with the fact that they operate for long periods (hours a day) means people find them intensely annoying.

Rock drills also create vibration from drilling, and the dominant frequency is governed by the rate at which the drill hammer strikes the drill string. This frequency is much higher than that of a hydraulic rockbreaker, and generally more tolerable. (The total energy imparted with each strike is also much smaller, so the peak velocity generated by drilling is less). Of course, while people prefer no noise at all from construction an operation, experience has shown noise and vibration from drilling is generally preferable to that of rock hammering.

The frequencies created during a blast depend largely on the nature of the rock between the blast and the monitoring point, but also on the distance from the blast, the blast initiation sequence, and the way the vibration monitor is mounted in the earth (coupling). When measurement is conducted in the near field (i.e. the distance to the monitor is comparable to the dimensions of the blast), a good blast designer can sometimes use advanced blasting techniques to create higher dominant vibration frequencies. If frequency based vibration limits are used, this is advantageous as it means higher velocities are allowed, and the blasting can be completely safer, faster and cheaper than otherwise.

### **Understanding the relationship between Frequency, Velocity and Displacement**

We cannot correlate acceleration, velocity and displacement directly; it is meaningless to ask for a conversion from “g” to “mm/s”, or “mm/s” to “mm”. To correlate one measure to another we need some information about the time period over which the event occurred - the “frequency” of the waveform. Frequency is measured in units of time; it is the number of cycles per second, measured in Hertz (Hz).

If we measure any of these parameters over time, we get a “waveform”, which we can analyse to infer the value of the other two parameters. This is normally done using computer software. However, by using a simple analogy we can understand the general nature of the relationship between them. Let's take as an example the relationship between velocity, displacement and frequency.

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Consider you drive to the shops and back as many times as you can in one hour. You will achieve more trips per hour if the shops are closer, than if they are further away. For a given peak velocity (your maximum driving speed), you will achieve a greater displacement (distance from home) with a lower frequency (number of trips per hour). Conversely for a given peak velocity, you will achieve a lower displacement (distance from home), if your frequency is high i.e. if you are driving at the same speed, the shops must be closer if you are able to increase the number of your trips.

This example shows the relationship between velocity, displacement and frequency that also applies to blasting vibrations. For a given peak velocity, the ground displacement is less if the waveform contains high frequencies. This principle is the basis of “frequency based criteria”. Frequency based criteria don’t just specify the maximum allowable velocity as a measure the potential for damage from a blasting vibration. Rather than just specifying the maximum allowed velocity, these criteria recognise that vibrations at high frequency only cause small displacements, and therefore are less likely to cause damage. Hence, the maximum allowable velocity depends on the frequencies the blast waveform contains. A high vibration level does not have to mean large displacements or damage.

Unfortunately for blasting practitioners, many people who are unfamiliar with blasting or physics don’t understand what “velocity” really means, or the relationship between velocity, displacement, frequency, and the potential for damage. In the following example, the peak velocity recorded was 18.82mm/s with a displacement of 0.038mm - the approximate width of a (thin) human hair.

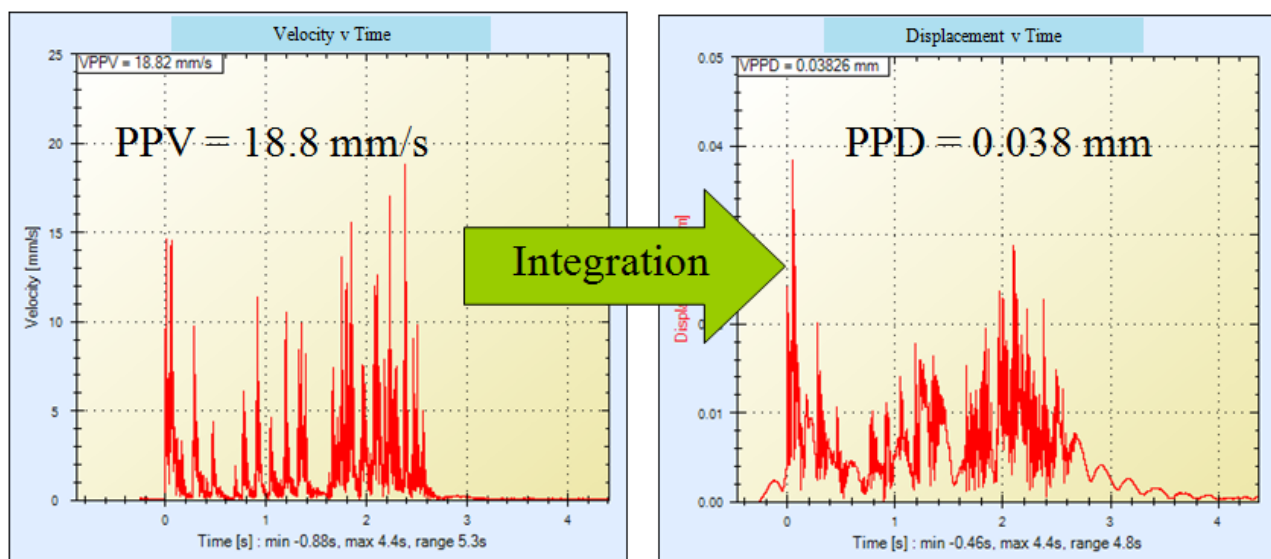


Figure 4: Integration of Velocity over time into Displacement

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While the velocity of 18.82 mm/s is higher than some of the common vibration guidelines, the likelihood of damage to nearby structures was very small because the frequencies were high, and the corresponding displacements were very small.

Therefore, when analysing vibration levels and selecting safe limits for a quarry operation or construction project, it is very important to consider the range of frequencies in the vibration waveform as well as the peak velocity.

### **Human Nature and the Perception of Blast Vibrations**

Many people do not realise that we tolerate similar, and often higher, vibration levels than those suggested in the relevant legislation and standards. These vibrations can come from everyday sources in the house and during daily routines, eg, a clap of thunder, a door closing, a child running down a hallway, or a windy day. However when people hear the word “blasting” it often generates an emotive response and they become sensitive to the resultant vibration despite the fact they regularly tolerate high levels from other sources.

Laboratory research and field experience has shown humans are not good at distinguishing between different magnitudes of vibration. People unaccustomed to blast effects can also find it difficult to distinguish between blast-induced ground vibrations and airblast (overpressure). Therefore, regardless of the limits chosen for a project and the blaster’s success in complying with them, people may still be inclined to complain about blast vibrations and/or overpressure. The overriding factor will often be the community’s attitude to the blasting rather than the actual blast vibration intensity.

Successful management of airblast and vibration relies as much (if not more) on community relations as it does on complying with imposed limits. Experience has shown that people can be willing to tolerate short bursts of high vibration from blasting as long as they are made aware of precisely when it is going to happen by suitable pre-blast warnings. This is especially so if they know that the alternative to blasting is long periods of mechanical rock breaking. Many adverse reactions to blast vibrations are the result of a resident being surprised and startled by the event simply because they weren’t told. Therefore, if good systems can be adopted for ensuring everyone in the surrounding area is aware of the impending blast, complaints are far less likely and higher vibrations levels are more likely to be tolerated.



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*Image 2: Orica Quarry Services blasting close to the community at a Quarry in South Australia.*

### Relevant References for Limits

In Queensland, specific limits may be set by:

- The Department of Employment, Economic Development and Innovation;
- The Department of Environment and Resource Management;
- The Local Council; and/or,
- The Owner of an asset.

### **Australian Standard 2187.2**

AS 2187.2 Appendix J informatively<sup>1</sup> describes various well-known criteria used in other standards but does not attempt to prescribe specific limits. The most important points in this Appendix are:

- Statutory limits applied for human comfort in specific jurisdictions may override the guidelines of Appendix J;

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<sup>1</sup> Informatively – means the AS2187.2 App J limits are guidelines rather than prescriptive rules.



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- Frequency dependent criteria should be used wherever possible, and are the “best practice”;
- Different limits may be applied depending on whether:
  - the receiver is occupied;
  - the receiver is “sensitive” or “non-sensitive”; or
  - the blasting project is short term or long term (less than or greater than 12 months or 20 blasts).

The Australian Standard also references the British Standard (BS 7385-2) with respect to vibration values that would be suitable to prevent the likelihood of “cosmetic” damage. The figure below shows these limits of 50mm/s at a frequency of 4Hz and above for industrial buildings, and between 15mm/s at 4Hz to 20mm/s at 15Hz increasing to 50mm/s at 40 Hz and above (**Error! Reference source not found.5**).

TRANSIENT VIBRATION GUIDE VALUES FOR COSMETIC DAMAGE (BS 7385-2)			
Line	Type of building	Peak component particle velocity in frequency range of predominant pulse	
		4 Hz to 15 Hz	15 Hz and above
1	Reinforced or framed structures. Industrial and heavy commercial buildings	50 mm/s at 4 Hz and above	
2	Unreinforced or light framed structure. Residential or light commercial type buildings	15 mm/s at 4 Hz increasing to 20 mm/s at 15 Hz	20 mm/s at 15 Hz increasing to 50 mm/s at 40 Hz and above

NOTES:

- 1 Values referred to are at the base of the building.
- 2 For line 2, at frequencies below 4 Hz, a maximum displacement of 0.6 mm (zero to peak) should not be exceeded.

Figure 5: Vibration Guide Values for Cosmetic Damage (AS2187.2)

As a general guide, AS2187.2 suggests the following limits but allows for higher limits to be negotiated with the affected parties:

- a frequency based limit of up to 50mm/s for control of threshold damage;
- an ultimate limit of 100mm/s for control of damage to unoccupied steel and concrete structures;
- a human comfort limit of 5mm/s (long term) and 10mm/s (short term) for sensitive receivers such as houses, schools, libraries, theatres etc
- a human comfort limit of 25mm/s for non-sensitive receivers, such as industrial or commercial premises.

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The Standard then goes on to suggest that if cordial relations can be maintained with a neighbour, then higher vibration limits may be negotiated and tolerated. In situations where the neighbour is going to benefit from the blasting (e.g. installation of a badly needed sewer, water main, or reduced duration of mechanical rock breaking), levels in excess of those stated for human comfort may be negotiated.

### **Queensland Explosives Act and Regulation**

The Explosives Regulation 2003 states that explosives shall be used by a prescribed shotfirer according to AS2187.2 (or alternative safety measures for the standard), and users shall take all reasonable steps to minimise the adverse effects of ground vibration. No specific vibration limits are set or discussed beyond the reference to AS2187.2. (For details of AS2187.2, see below.)

### **Queensland Environmental Protection Act**

The Environmental Protection Act 1994 (EP Act) applies a frequency based limit of 10mm/s if less than 35 Hz and 25mm/s above 35 Hz. This reflects the United States Bureau of Mines (USBM) “safe” blasting criteria referenced in AS2187.2 appendix J (Figure 6).

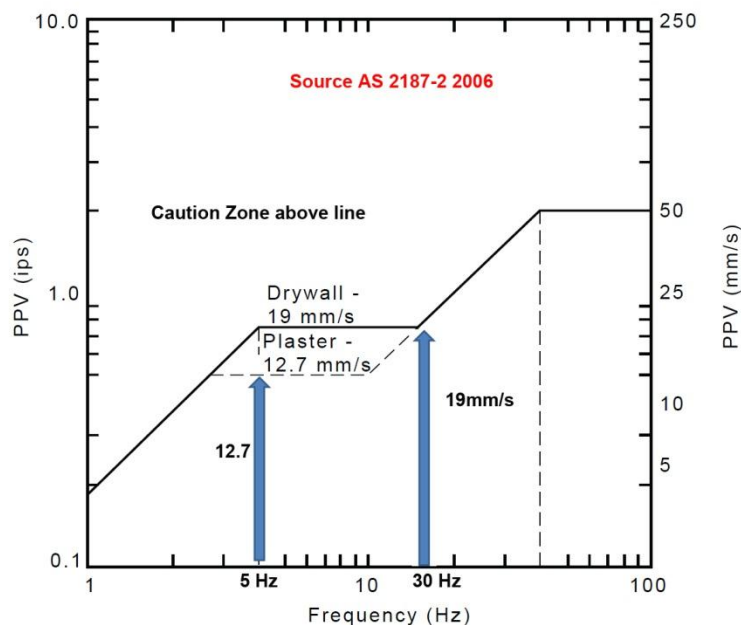


Figure 6: USBM "Safe" Blasting Vibration Criteria (AS2187.2)

In most civil construction blasting projects and some quarry sites, where measurement is conducted in the near field (i.e. the distance to the monitor is comparable to the dimensions of the blast), a good blast designer can use advanced blasting techniques to channel vibration frequencies above 35Hz, and thus the limit of 25mm/s would apply.

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Unlike AS2187.2, the EP Act makes no distinction between occupied and unoccupied structures. It does, however, state that “noise” includes vibration of any frequency, whether emitted through air or another medium, and that such emissions may be investigated if a complaint is made.

The Department of Environment and Resource Management (previously known as the Environmental Protection Agency) has also previously issued the Ecoaccess “Guideline for Noise and Vibration from Blasting” (dated 23/3/2006). This document includes slightly different limits than the EP Act and refers to a limit of 5mm/s for nine out of ten blasts, and an overall limit of 10mm/s, regardless of frequency. It also restricts blasting to times between 9:00am and 3:00pm despite most authorities allowing blasts to be fired well outside these hours (typically between 6:00am and 6:00pm).

### **Local Council Laws**

As detailed in AS2187.2, local jurisdictions may apply specific criteria for human comfort. It is the authors’ experience that local councils often have no written guidelines or limits. The most common illustration of this is a blanket limit of 10mm/s applied regardless of waveform frequency, blasting regularity or occupied status of the structure. In contrast, the revised Australian Standard AS 2187.2 considers waveform frequency, blasting frequency and occupied status.

### **Owner of asset**

The blasting contractor is usually required to contact the owners of any assets which may be affected by blasting. In the authors’ experience, some asset owners will impose prohibitively conservative limits on their infrastructure e.g. choosing low “Human Comfort” limits for steel and concrete. This can make blasting very inefficient, which can have a large impact on the success of a project. Therefore it is important to meet with the owners early, to discuss their concerns, and help them understand the true effect of vibration on their particular asset.

### **The Cost of Lower Limits**

In a desire for “total compliance”, those who set the limits for blasting often select the lowest value (5mm/s or 10mm/s), in the mistaken belief that a lower limit will be better for the community, and without consideration of the true environmental implications or added project costs.

The chart below shows the general relationship between the unit cost of drill and blast (\$ per cubic metre), project duration, and the vibration limit selected. Choosing lower limits quickly increased the cost and duration of the project. This is mainly because smaller holes must be used, and hence many more holes are required. Consequently, the total hours of drilling increases, as do the number of blasts. Hence, the overall impact of the project on neighbours becomes worse.



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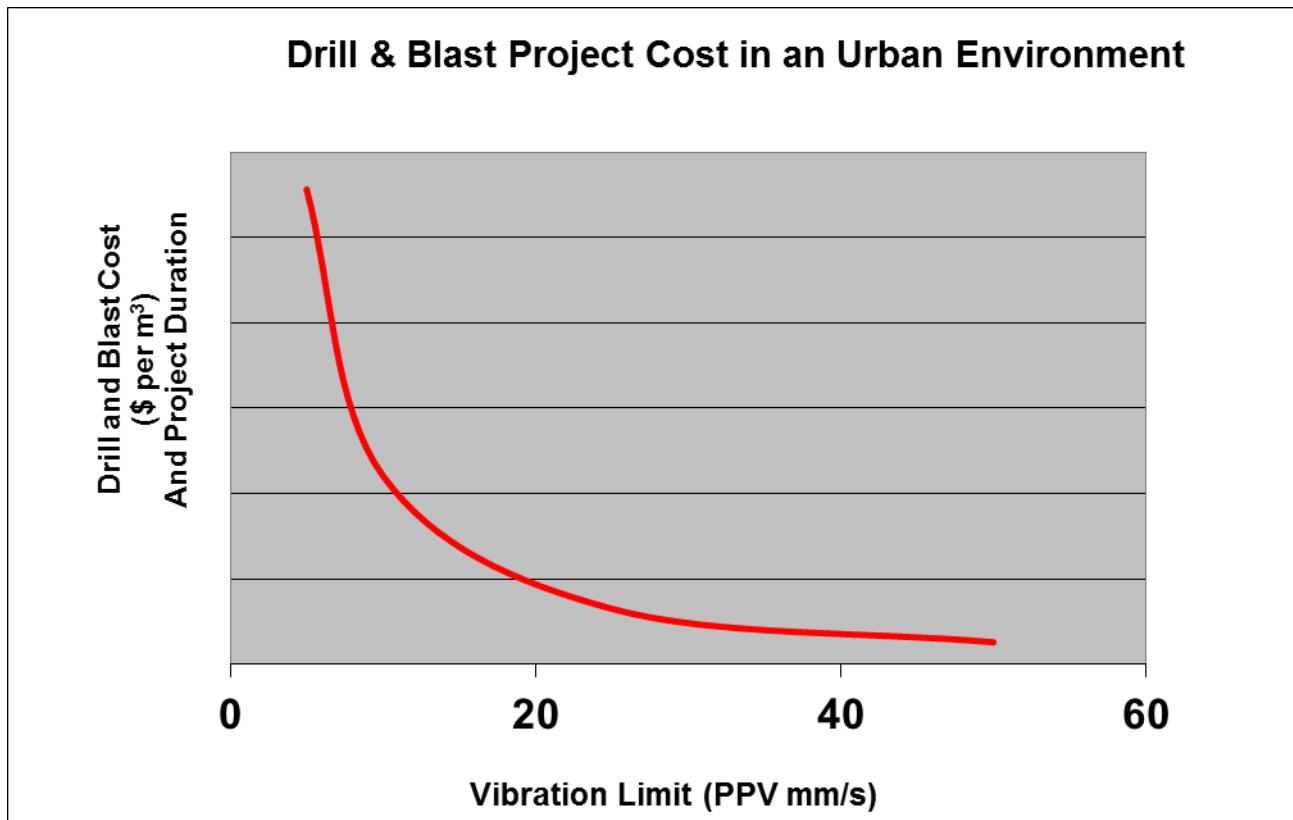


Figure 7: Cost and Duration of a Fixed Volume Blasting Project based on Vibration Limit

Table 1, below, compares the relative cost and duration of blasting 15,500 bank cubic metres (BCM) in an urban environment in compliance with various vibration limits from different standards and guidelines. The data clearly shows the exponential rise in project cost and duration as lower vibration limits are imposed. With increased project duration comes longer exposure to drilling noise, mechanical rock breaking, and many more interruptions for blasting.

Given that humans are poor at distinguishing between different magnitudes of blast vibration, one could argue that the lowest overall environmental impact is achieved by accepting a higher vibration limit with a consequential massive reduction in drilling noise and number of blast events. On civil construction projects, where vibrations are measured in the near field, the peak velocity is likely to be associated with relatively high frequencies and therefore very small displacements. Therefore, the risk of cosmetic damage at levels up to 50mm/s peak velocity is relatively low.

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Even if damage does occur, at these levels it will most likely be cosmetic rather than structural, and easily repairable. A simple economic analysis will easily show that a small portion of blasting cost savings will cover the contingency of repairs for cosmetic damage claimed.

*Table 1: Indicative Costs and Durations for Blasting 15,500BCM in an Urban Environment*

Vibration (PPV)	Limit	Total Cost	Cost/BCM	Blasts	Project Duration (Days)
<b>5</b>		A substantial portion of the volume cannot be blasted See note below			
5		\$721 433	\$72.14	18	108
10		\$938 495	\$60.54	15	90
25		\$479 315	\$30.92	7	42
50		\$244 450	\$15.77	3	18

Note: At 5mm/s, only 10,000BCM of the total volume can be blasted without exceeding the threshold limit, leaving 5,500 BCM to be mechanically rock broken at a significant cost to the project.

### Conclusion

The selection of suitable limits for blasting vibration should be based on a number of factors, including:

- Legislative regime (i.e. Council, Regulations, DERM or AS2187.2);
- Type of building (residential / commercial / industrial / light / heavy);
- Occupational status of building (ie occupied or not);
- Duration of project and frequency (time i.e. month/years and repetition) of blasting;
- Dominant frequency of the vibration waveform;
- Relationship with the owner / occupier / neighbour.

Ultimately the last factor in the list above, the attitude of the neighbours, can have far more bearing on the success of the project than any predetermined limit. Neighbours who are well informed are far less likely to complain and more likely to accept higher vibration levels, to the benefit of both themselves and the project. Experience has shown people can be tolerant of levels in excess of 50mm/s if:

- They understand the benefit of blasting vs extended rock breaking;
- They know exactly when the blast is about to fire and how long it will be;
- They know there will only be “x” number of blasts during the project;
- They will benefit in other ways from the blast (eg. installation of a badly needed infrastructure);
- They are confident their property will be competently assessed for damage and any proven damage (although unlikely) will be rectified.

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Therefore, if good systems can be adopted for ensuring everyone in the community is considered and consulted, complaints will be far less, and higher vibrations levels are more likely to be tolerated.

In order to ensure success, all parties involved in a project should have the opportunity to discuss and select the most appropriate limits in terms of overall environmental impact and cost efficiency. These discussions should take place prior to the commencement of the project, and should include advice from industry experts with experience in vibration management in close proximity blasting.

Finally, when analysing vibration levels and selecting limits which should apply to a quarry operation or construction project, it is essential to consider limits which have the lowest overall impact to the community. The impact upon people and property may be reduced by controlling not only the magnitude of vibration (velocity), but also by increasing the frequency at which it is generated. Therefore, serious consideration should be given to choosing and using frequency based criteria for safe blasting.

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