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**KALGOORLIE CONSOLIDATED GOLD MINES SUPER PIT
EFFECTS OF BLASTING IN THE GOLDEN PIKE CUT-BACK**

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27th February 2006

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KALGOORLIE CONSOLIDATED GOLD MINES SUPER PIT

EFFECTS OF BLASTING IN THE GOLDEN PIKE CUT-BACK

EXECUTIVE SUMMARY

Terrock Consulting Engineers were requested by Kalgoorlie Consolidated Gold Mines (KCGM) Pty Ltd to investigate the potential environmental effects of blasting during the Golden Pike cut-back.

The airblast and ground vibration measurements recorded at the six routine monitoring stations during the Chaffers West cut-back were analysed and models developed to permit prediction for the Golden Pike cut-back.

The ground vibration assessment (see **Appendices 3a** and **3b**) has shown that with worst-case assumptions, the maximum ground vibration levels resulting at privately owned houses from blasting at the pit perimeter will, in general, not exceed 5 mm/s. The average levels resulting at privately owned houses will be less than 2 mm/s. Maximum ground vibration levels resulting at the closest industrial buildings will, in general, not exceed 10 mm/s. The average levels resulting at the closest industrial buildings will be around 2 mm/s.

The airblast assessment (see **Appendices 4a** and **4b**) shows that for blasts at the pit perimeter, airblast levels at the closest privately owned houses will, in general, not exceed 115 dBL, with less than one in ten blasts resulting in airblast levels in the range 115-120 dBL. Airblast levels resulting from blasting at the pit perimeter at the nearby industrial buildings will, generally, be in the range 115-120 dBL, with levels at the closest industrial buildings reaching the range 120-125 dBL on occasions.

These airblast and ground vibration levels will be less for blasts located at greater distances and lower depths from the pit perimeter.

The accuracy of the models and the assumptions made in this investigation will be assessed by continuation of the blast vibration monitoring program, with continual review of the results and modification of the blasting specifications (and loading controls) as required.

The investigation has shown that the maximum airblast and ground vibration levels resulting from blasting in the Golden Pike cut-back will not exceed environmental standards and limits, and that average levels will be well below these.

1. INTRODUCTION

Terrock Consulting Engineers were requested by KCGM to investigate the environmental effects of blasting in the Golden Pike cut-back, particularly upon the residential areas of Kalgoorlie-Boulder. The Golden Pike cut-back is similar to the Chaffers West cut-back and so data from the Chaffers West cut-back was analysed to develop the blasting model. The location of the Golden Pike blasting is shown in **Appendix 1**. The ground vibration and airblast from blasts fired at KCGM is measured at six permanent monitoring stations, and are also shown in **Appendix 1**.

The effects of blasting investigated in this report are:

- Ground vibration.
- Air vibration (airblast or overpressure).

The data from over 140 Chaffers West cut-back blasts, which commenced in June 2003, was analysed and models developed to predict the extent of peak vibration levels from the Golden Pike cut-back.

2. BLASTING PRACTICE

For the benefit of those unfamiliar with blasting practice and blast vibration, a description is provided in **Appendix 2 – Explanatory Notes**.

2.1 Blast Specifications

2.1.1 Standard Super Pit Specifications

Details of standard blasting specifications used in the Super Pit are listed in **Table 1.1**. Separate specifications are shown for the oxidised or weathered zone, and for the sulphide zone or unweathered rock. A cut-back generally commences in oxidised material, which progresses to unweathered material after about four benches or at a depth of about 40-50 metres below ground surface (ie. RL110m-120m). As the rock passes from the oxidised zone to the sulphide zone, which occurs as a transition zone at variable depths, the blasting specifications are adjusted accordingly.

Table 1.1 – Details of Standard Super Pit blasting practice

	Unweathered (sulphide)	Weathered (oxidised)
Burden:	4.8 metres	4.8 metres
Spacing:	6.2 metres	6.2 metres
Drilling pattern:	staggered	staggered
Drilling depth:	11.3 metres	11.3 metres
Subgrade:	1.3 metres	1.3 metres
Blasthole angle – front row:	angled to achieve correct toe burden	angled to achieve correct toe burden
Blasthole angle – other rows:	vertical	vertical
Explosives Type:	Energan	ANFO
Stemming height:	4.1 metres	5.0 metres
Stemming material:	crushed aggregate (14–25 mm)	crushed aggregate (14–25 mm)
Downhole delays (Nonel):	No. 12	No. 12
Surface trunkline delay pattern (Nonel):	17 ms (spacing) x 65 ms (burden)	17 ms (spacing) x 42 ms (burden)
Electronic:	varied firing sequences	varied firing sequences

The vibration levels for every blast are measured. The models are progressively reviewed and updated so that the specifications can be modified if and when required to ensure compliance with the regulatory standards and limits. A detailed understanding of the mechanisms causing blast vibration ensures that the residential areas of Kalgoorlie-Boulder are exposed to the lowest practicable levels of vibration.

2.1.2 Proposed Golden Pike Specifications

The blasting practice proposed for the Golden Pike cut-back is based on current practice used in the Super Pit, together with modified practice used in the Chaffers West cut-back and the analysis of data obtained during this investigation.

Details of the proposed Golden Pike blasting specifications are listed in **Table 1.2**.

Table 1.2 – Details of proposed Golden Pike blasting practice

	Unweathered (sulphide)	Weathered (oxidised)
Burden:	4.8 metres	4.8 metres
Spacing:	6.2 metres	6.2 metres
Drilling pattern:	staggered	staggered
Drilling depth:	11.3 metres	11.3 metres
Subgrade:	1.3 metres	1.3 metres
Blasthole angle – front row:	angled to achieve correct toe burden	angled to achieve correct toe burden
Blasthole angle – other rows:	vertical	vertical
Stemming height:	4.1* metres	5.0* metres
Stemming material:	crushed aggregate (14–25 mm)	crushed aggregate (14–25 mm)
Electronic:	varied firing sequences	varied firing sequences

Note: Stemming height may be increased up to 5.5 metres as required to ensure compliance with environmental standards and limits at houses.

Most blasting is carried out using vertical 165 mm diameter blastholes. At the pit perimeter a number of 115 mm diameter holes are drilled at an angle to form the final batter. The explosives used range from ANFO with a density of 0.8 g/cc to ENERGAN 2660 with a density of 1.3 g/cc. The charge mass for a standard 11.3 metre deep hole with 4.1 metre and 5 metre stemming heights are listed in **Table 2**. ANFO is used whenever possible in dry blastholes. Emulsion explosives are used in blastholes that contain water.

Table 2 - Charge mass for a standard 11.3 metre deep hole with 4.1 metres and 5 metres stemming heights

Explosive	Density (g/cc)	Mass per metre @ 165 mm diameter (kg)	Charge mass per hole 4.1 metres stemming (kg)	Charge mass per hole 5 metres stemming (kg)
ANFO	0.8	17.1	123	108
ENERGAN 2620	1.0	23.5	169	148
ENERGAN 2640	1.2	25.7	185	162
ENERGAN 2660	1.3	27.8	200	175

Because the blasting closest to houses will be in the oxidised zone with dry holes, the predictive analysis of blast vibration levels resulting from blasts located at the pit perimeter has been carried out using a charge mass per hole of 108 kg.

2.3 Safety and Quality Assurance Checks

Safety and quality assurance checks which will be used in the Golden Pike cut-back to control ground vibration, airblast, rock displacement and flyrock are outlined in **Table 3**.

Table 3 - Outline of safety and quality assurance checks

Item	Details
Face surveying:	Visual checks of the existing situation are made by the shotfirers.
Blasthole collar layout:	All standard blasthole collars are set out with survey control, except for front row collar positions, which are set out based on the judgement of shotfiring personnel regarding conditions existing.
Front row hole burdens:	The front row of blastholes is inclined (using the judgement of shotfiring personnel) to achieve the correct toe burden of 4.8 metres.
Blasthole drilling depths:	As required (based on survey advice) to achieve the required level – generally 11.3 metres to 12.0 metres below collar. The depth of each blasthole is checked by the driller, and Q.A. officer, and backfilled as required to the correct level. Holes of insufficient depth are redrilled before loading.
Explosives charge mass per hole – front row blastholes:	Front row blastholes are light loaded, based on the judgement of the shotfirer, with increased stemming height as appropriate to compensate for reduced burden or weak ground conditions.
Explosives charge mass per hole:	Each blasthole is charged to ensure either minimum design stemming height or maximum design charge mass.
Explosives charge – column length:	The height of the explosive charge is checked to determine if cavities exist (in the case of insufficient column rise) and to prevent an inadequate stemming height.
Stemming height:	The explosives column height is checked with a loading pole to ensure the correct stemming height is achieved

2.4 Evaluation of Blasting Practice

Rock displacement and flyrock is evaluated by visual observation and replay of the video recordings that are taken of blasts.

Airblast overpressure and ground vibration is measured at up to six monitoring stations located at the edge of the housing area, immediately west of the pit. The locations of the monitoring stations are shown on the location plan, which is attached as **Appendix 1**.

The recorded measurements are reviewed for blasting and compared to environmental standards and limits. Additional vibration performance evaluation may also be conducted, eg. stemming performance by inspection of wavetraces. Other blasting factors, such as fragmentation and loading efficiency, are evaluated as part of effective mine management.

3. VIBRATION STANDARDS AND LIMITS

The current vibration standards and limits are specified in the 'KCGM Noise and Vibration Monitoring and Management Programme':

3.1 Ground vibration

Ground vibration from open pit blasting will not exceed the Australian Standard (AS2187.2-1993) of 10 mm/s at houses. No more than one in ten consecutive blasts will exceed 5 mm/s at houses.

3.2 Airblast Overpressure

Between 07:00 and 18:00 hours Monday to Saturday:

- Airblast overpressure from blasting will not exceed 125 dBL (linear peak) at houses.
- No more than 1 in 10 consecutive blasts will exceed 120 dBL (linear peak) at houses.

Between 07:00 and 18:00 hours on a Sunday or public holiday:

- Airblast overpressure from blasting will not exceed 120 dBL (linear peak) at houses.
- No more than 1 in 10 consecutive blasts will exceed 115 dBL (linear peak) at houses.

4. ASSESSMENT OF ENVIRONMENTAL EFFECTS

Detailed analyses of the results of environmental monitoring conducted for over 140 Chaffers West area blasts from 6th June 2003 to 18th March 2004 were conducted. The blast vibration levels were recorded at six monitoring stations. The levels recorded at the three monitors closest to the Boulder township (Delta, Echo, and Foxtrot) were analysed in detail. The blasts were located from the RL70 bench to the RL120 bench.

A summary of the analyses is given in this section.

The basic model for ground vibration analysis and prediction used is:

$$V = k_v \left(\frac{D}{\sqrt{m}} \right)^{-1.6} \quad [1]$$

where: V = peak particle velocity (mm/s)
 D = distance (m)
 m = charge mass per hole (kg)
 k_v = site constant (ground)

4.1 Ground Vibration

The range of peak particle velocities (PPVs) and distances to each of the three monitors are listed in **Table 3**, together with the determination of the worst case k_v.

Table 3 – Blast vibration summary

Monitoring Station	Range of Distances (m)	Range of PPVs (mm/s)	Average (k_v)	Peak (k_v)
Delta	474-1088	0.25-2.57	827*	1677*
Echo	379-953	0.33-3.19	790	1565
Foxtrot	454-938	0.24-1.53	508	1379

* used in the estimates

The relationship between vibration and distance for a 108 kg charge mass, using k_v factors of 827 and 1677, is shown in **Table 4** and **Figure 1**.

Table 4 – Relationship between vibration and distance for standard 108 kg charge mass

PPV (mm/s)	Distance (m) with $k_v = 827$	Distance (m) with $k_v = 1677$
25	92	144
10	164	255
5	253	394
2	448	698
1	692	1077

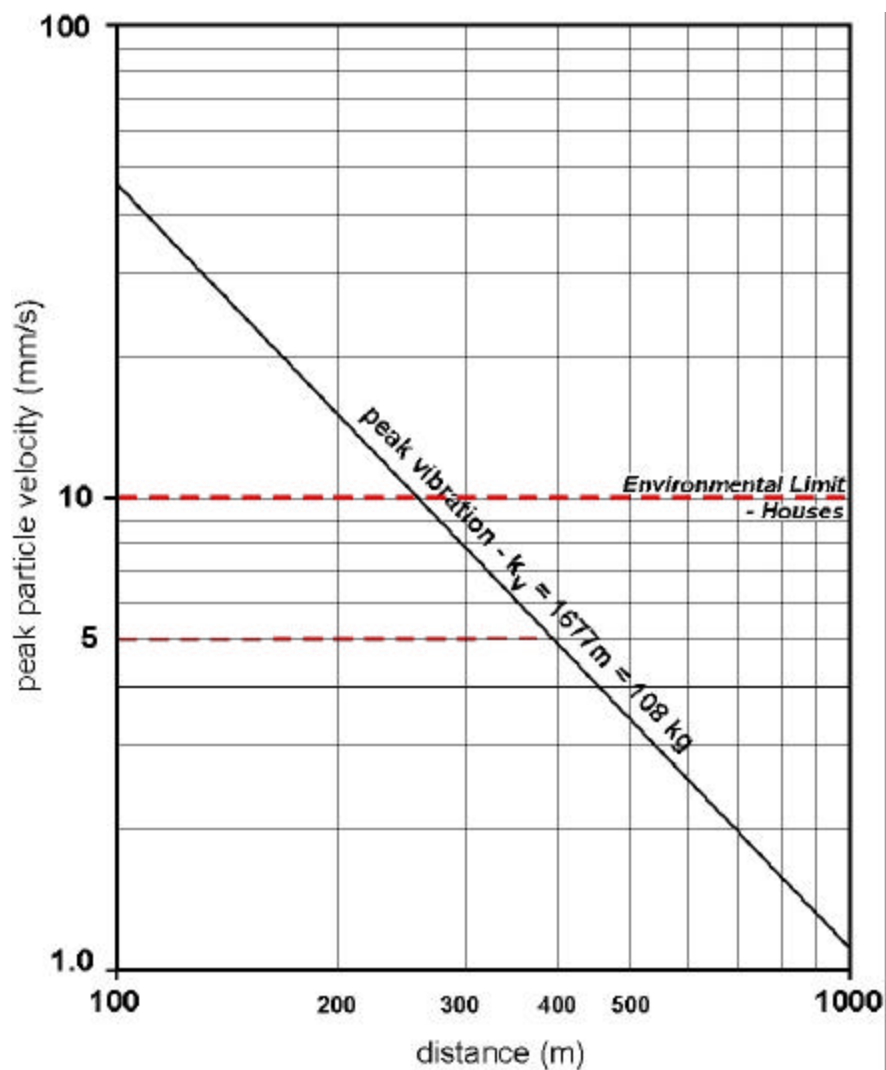


Figure 1 – The relationship between peak ground vibration (PPV) and distance (m = 108 kg)

To demonstrate the maximum ground vibration levels that any house in Kalgoorlie-Boulder will be exposed to, the single blast contours (for $k_v = 1677$, and charge mass = 108 kg) were moved along the extraction limit and the furthest extent of the 2 mm/s, 5 mm/s and 10 mm/s levels were plotted, as shown in **Appendix 3a**.

The assessment shows the maximum vibration levels that will be received in Kalgoorlie-Boulder from any blast at the nearest location in the pit during the Golden Pike cut-back. The maximum ground vibration from blasts at the pit perimeter will not exceed 5 mm/s at any house not owned by KCGM.

To demonstrate an average situation, or the levels that houses will be exposed to for approximately half the blasts, the contours using $k_v = 827$ were moved along the mid-point of the cut-back area, as shown in **Appendix 3b**. This assessment shows the levels that houses will be exposed to for approximately half the blasts in the Golden Pike cut-back. Houses not owned by KCGM, on average, will be exposed to less than 2 mm/s.

The Australian Standard for houses is 10 mm/s. Some Kalgoorlie-Boulder citizens become concerned at vibration levels at about 5 mm/s when the blast vibration lasts for periods longer than 3 seconds. The blast duration in this instance was more significant than the PPV level as such. The use of electronic detonators provided an effective means of reducing the level of concern by permitting several shorter duration blasting sequences to be fired in each blast with a short time delay between each blasting sequence. The electronic initiation methods used also reduced the peak ground vibration by at least half for most blasts. With further investigation, initiation sequences that resulted in reduced ground vibration could be identified and a consistent reduction in ground vibration may result.

All blasts in the Golden Pike cut-back should be fired with initiation sequences that have been evaluated before firing to ensure compliance with the Australian Standard. If routine monitoring shows that the standard may be exceeded, blast vibration will be further reduced with a modification of blasting specifications.

4.2 Airblast

The airblast levels resulting from blasting during the Chaffers West cut-back at the three monitoring stations nearest the Boulder township, namely Delta, Echo and Foxtrot, were analysed using an airblast model developed by Terrock.

The model in its' simplest form is:

$$D_{120} = \left(\frac{k_a \times d}{S.H.} \right)^{2.5} \cdot \sqrt[3]{m} \quad [2]$$

where:

- D_{120} = distance to the 120 dBL contour (m)
- d = hole diameter = 165 mm
- $S.H.$ = stemming height (mm)
- m = charge mass per hole (kg)
- k_a = an empirical site constant

Analysis of the Chaffers cut-back data showed that a k_a of 160 was appropriate for future worst-case prediction airblast. The range of peak airblast levels recorded is listed in **Table 5**.

Table 5 - Range of peak airblast levels

Monitoring Station	Distance Range (m)	Peak Airblast Range (dBL)
Delta	474-1088	106.8-123.0
Echo	379-953	111.6-126.7
Foxtrot	454-938	108.2-122.0

The peak air vibration levels came from blasts on the RL70m or RL80m benches, where there is a minimum of shielding. In general, measurements in excess of 120 dBL were recorded before the stemming height was increased to 5 metres. Measurements in excess of 120 dBL after the stemming height increase were probably due to inaccurate implementation of the design.

Subsequent check measurements of stemming heights in 2004 confirmed that a substantial variance from design was achieved during normal loading practice, with 15 % of blastholes having stemming heights 0.9 metres less than design, which accounts for the higher airblast levels.

A more rigorous loading regime is proposed during the Golden Pike cut-back that is consistent with a 200 metre blast clearance area. This improved loading practice will also produce consistently lower airblast emissions.

The airblast predicted from the model is demonstrated in **Figure 2** and **Table 6** for different stemming heights. The increase in airblast levels due to variation in stemming height, can be seen. The peak airblast levels from blasting in the Chaffers West cut-back measured at the Delta, Echo, and Foxtrot monitors are also listed in **Table 5**.

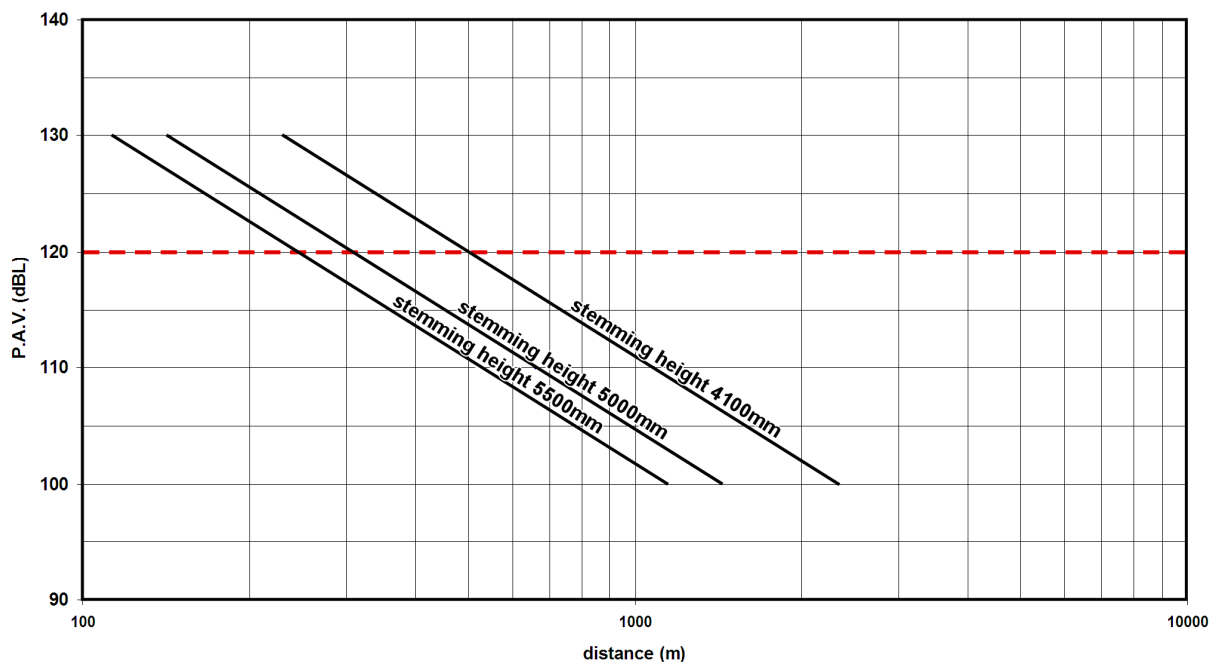


Figure 2 – Predicted airblast

Table 6 – Predicted airblast level distances for difference stemming heights

Airblast (dBL)	Distance Stemming Height 4100 mm (m)	Distance Stemming Height 5000 mm (m)	Distance Stemming Height 5500 mm (m)
125	340	210	170
120	500	310	240
115	740	450	350
110	1080	660	520
105	1580	970	760

The peak predicted airblast levels for a single blast, with a 5 metre stemming height and 108 kg charge mass, are shown in contour form in **Figure 3**. To demonstrate the highest airblast levels the houses in Kalgoorlie-Boulder would be exposed to, these single blast contours were moved along the pit perimeter and the furthestmost extent of airblast levels into Kalgoorlie-Boulder were determined and are shown in the airblast assessment **Appendix 4a**. The assessment shows that for blasts at the pit perimeter, airblast levels at the closest privately owned houses will in general be around 115 dBL, with less than 1 in 10 blasts resulting in airblast levels in the range 115-120 dBL. Airblast levels resulting from blasting at the pit perimeter at nearby industrial buildings will generally be in the range 115-120 dBL, with levels at the closest industrial buildings reaching the range 120-125 dBL on occasions.

To demonstrate an average exposure from RL70m and RL80m benches, the contours were moved along the mid-line of the cut-back area, the maximum extent of the contour levels are shown in **Appendix 4b**. The average airblast assessment shows that airblast levels resulting from blasting at the perimeter, airblast levels at the closest privately owned house will be less than 115 dBL, and will not exceed 120 dBL at any building.

The predicted airblast levels are conservative because they assume the environmental noise bund will provide no shielding. The bunding is expected to provide between 1-3 dBL shielding for the upper benches (-70m and -80m) increasing as the pit deepens. If routine monitoring shows that airblast limits may be exceeded, further reduction in airblast can be achieved by increasing the stemming heights for blasts approaching the pit perimeter.

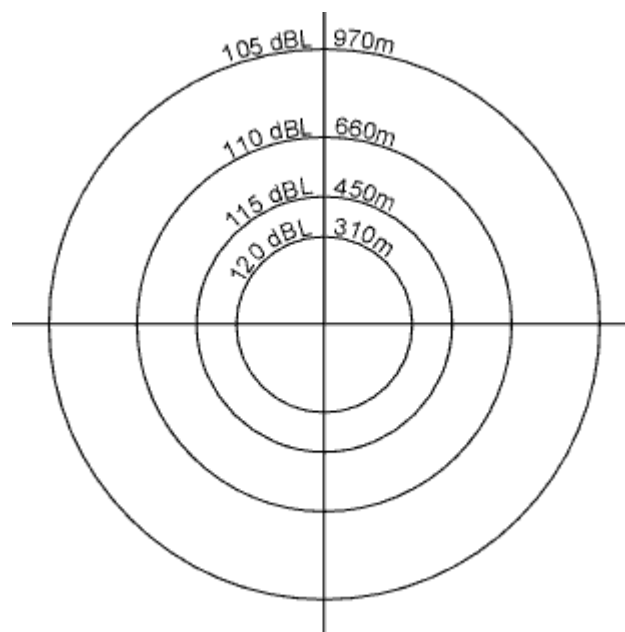


Figure 3 - Peak predicted airblast levels

5. ENVIRONMENTAL MANAGEMENT PLAN

The air and ground vibration from all blasts should continue to be monitored at locations that reflect the levels of vibration the residential areas of Boulder are subject to, ie. Alpha, Charlie, Delta, Echo and Foxtrot. The Bravo monitor will be relocated as its current position is under the footprint of the proposed realigned environmental noise bund.

The results should be reviewed after each blast and blasting specifications (stemming height and initiation sequence) and/or loading procedures modified if necessary to prevent exceedences occurring.

6. CONCLUSIONS

Analysis of the blast vibration measurements from 140 Chaffers West cut-back blasts has permitted the calibration of models that can be used for the future prediction of ground vibration and airblast during the Golden Pike cut-back.

The ground vibration assessment (see **Appendices 3a** and **3b**) has shown that with worst-case assumptions, the maximum ground vibration levels resulting at privately owned houses from blasting at the pit perimeter will not exceed 5 mm/s. The average levels resulting at privately owned houses will be less than 2 mm/s. Maximum ground vibration levels resulting at the closest industrial buildings will not exceed 10 mm/s.

The airblast assessment (see **Appendices 4a** and **4b**) shows that for blasts at the pit perimeter, airblast levels at the closest privately owned houses will in general not exceed 115 dBL, with less than one in ten blasts resulting in airblast levels in the range 115-120 dBL. Airblast levels resulting from blasting at the pit perimeter at nearby industrial buildings will generally be in the range 115-120 dBL, with levels at the closest industrial buildings reaching the range 120-125 dBL on occasions.

These airblast and ground vibration levels will decrease for blasts located at greater distances and lower depths from the pit perimeter.

The accuracy of the models and the assumptions made in this investigation will be assessed by the continuation of the blast vibration monitoring program, with continual review of the results and modification of the blasting specifications (and loading controls) as required.

The investigation has shown that the maximum airblast and ground vibration levels resulting from blasting in the Golden Pike cut-back will not exceed environmental standards and limits, and that average levels will be well below these.

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27th February 2006

APPENDICES

APPENDIX 1 – LOCATION PLAN



APPENDIX 2 - BLASTING PRACTICE THE NATURE OF VIBRATIONS AND ITS MEASUREMENT AND CONTROL - EXPLANATORY NOTES

A1. SUPER PIT BLASTING PRACTICE

These notes were written to explain, in simple terms, the nature of blast vibration and how it is measured.

To extract rock economically in mines it is necessary to blast the rock with explosives. It is necessary to place the explosives within the rock mass by drilling blastholes downward into the rock. A quantity of explosives is then placed in each blasthole, which is then topped up with crushed aggregate to effectively confine the explosives charge. Current blasting practice at the Super Pit is described below.

Production blastholes, 165 mm diameters are drilled in rows 4.8 metres apart (burden) and are spaced 6.2 metres apart, as shown in **Figure A2.1**.

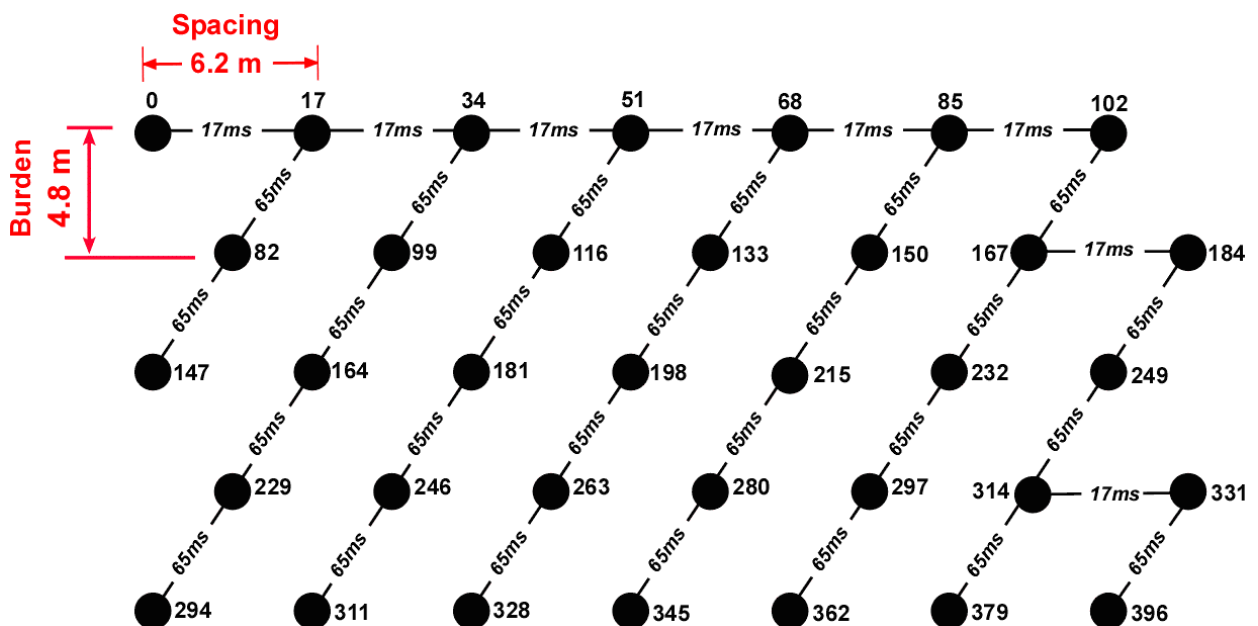


Figure A2.1 – Typical drilling pattern and initiation timing

The burden and spacing are varied to match the characteristics of the rock being blasted.

The production holes are drilled vertically to a depth of 11.3 metres. To form a stable final wall, the pattern is modified towards the extraction limit to incorporate buffer and batter holes. The batter holes are 140 mm diameter and drilled at an angle to form the final wall, as shown in **Figure A2.2**.

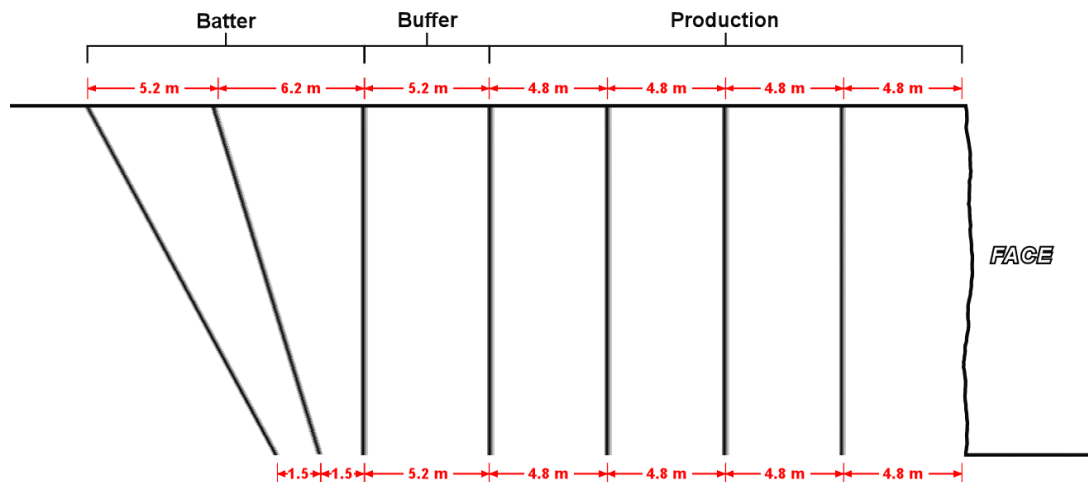


Figure A2.2 – Final wall drilling design

Explosives are then loaded into the blasthole until the top of the explosive charge is no closer than 4.1 metres from the top of the blasthole. The hole is then topped up with at least 4.1 metres of stemming to effectively confine the explosives charge, as shown in **Figures A2.3a-b**.

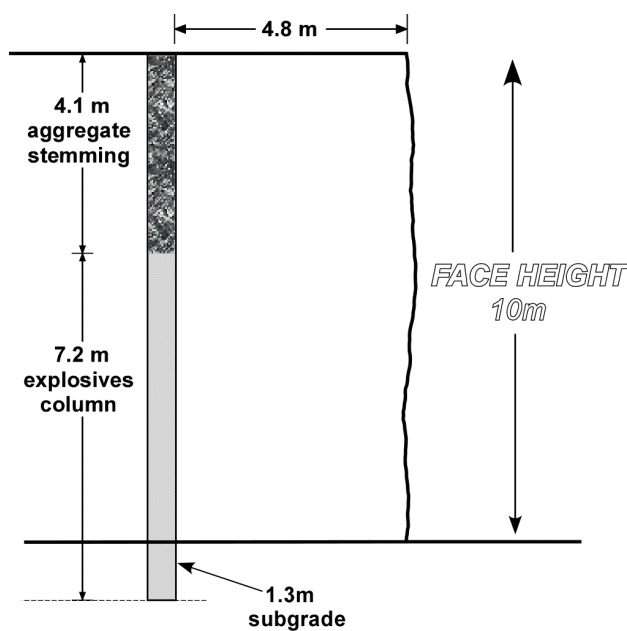


Figure A2.3a - Typical hole loading – sulphide zone

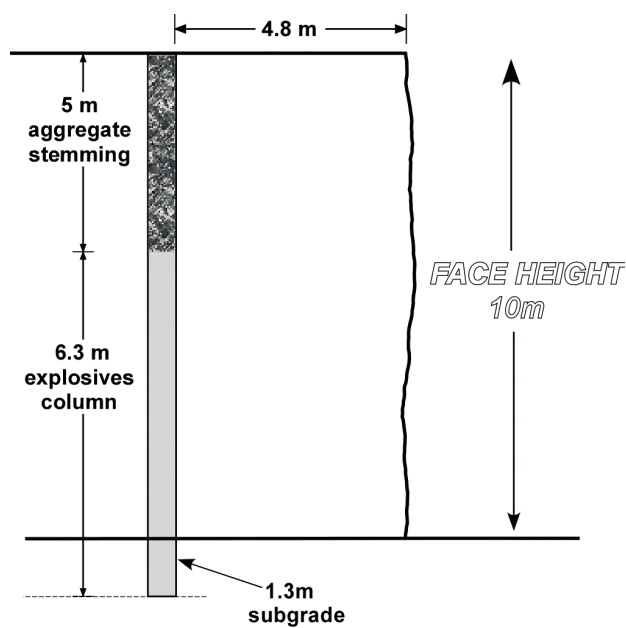


Figure A2.3b - Typical hole loading – oxide zone

It is common mine practice for the number of blastholes loaded and fired in any one blast to vary up to hundreds of holes. Signal tube delay detonators initiate the explosives in each blasthole.

The signal tube leads from each blasthole are joined together by surface signal tube delay detonators to form a blasting circuit. At the approved firing time, after warning signals have been given, the blasting circuit is connected to an exploder and fired.

All blastholes do not, however, explode at the same instant of time. Reduced blast vibration and improved fragmentation result because the blastholes detonate in sequence, with a small time delay of several milliseconds between each explosion. This small time delay is provided by the surface signal tube delay detonators and an unlimited number of delay intervals are possible. It is usual for only one blasthole to be exploded at any instant of time. In the case of a number of blastholes being fired in the one blast, a possible delay sequence is shown in **Figure A2.1**.

The blastholes at one end of the blast explode first, and are followed by the succeeding blastholes in the sequence shown. The total time for the 35 blastholes to be exploded would be 396 milliseconds (less than half a second). The total time for 200 blastholes in a pattern 20 holes long by 10 rows deep would be 1160 milliseconds. After the blast, the broken rock is left lying in a heap in its original position; the broken rock is then loaded into trucks and taken to the crusher if it is ore or to a waste dump.

It was found that upon commencement of the Chaffers West cut-back some residents became concerned if the blast vibration lasted longer than about 3 seconds, even at levels well below the environmental standards and limits. To address these concerns, electronic detonators were used to reducing the level of concern by permitting several shorter duration blasting sequences to be fired in each blast with a short time delay between each blasting sequence. This had the effect of halving the levels of blast vibration for most blasts as well as reducing the structural response time. The cause of the concern was the audible structural response of buildings when the time period (and subsequent vibration effect) for each blasting sequence vibration was prolonged. Electronic detonation, or equivalent initiation systems, should be considered for the upper benches of the Golden Pike cut-back.

A2. THE NATURE AND MEASUREMENT OF BLAST VIBRATION

Explosive energy produces the following effects:

- Rock shattering and displacement.
- Ground vibration.
- Air vibration.

The energy contained in explosives used in mine blastholes is designed to break and displace rock, and the more energy available, which can be utilised for that purpose, the more efficient the blast. However, some of the energy cannot be utilised in breaking rock and creates vibration in the surrounding rock and air.

As a general principle, both air and ground vibration increase with increasing charge mass and reduce with increasing distance.

A2.1 Ground Vibration

Ground vibration radiates outwards from the blast site and gradually reduces in magnitude, in the same manner as ripples behave when a stone is thrown into a pool of water, schematically shown in **Figure A2.4**. The motion of the wave can be defined by taking measurements of a float on the surface of the water. With suitable instruments the displacement or amplitude, the velocity, the acceleration of the float and the wave length of the waves can be measured.

Blast Vibration Terminology

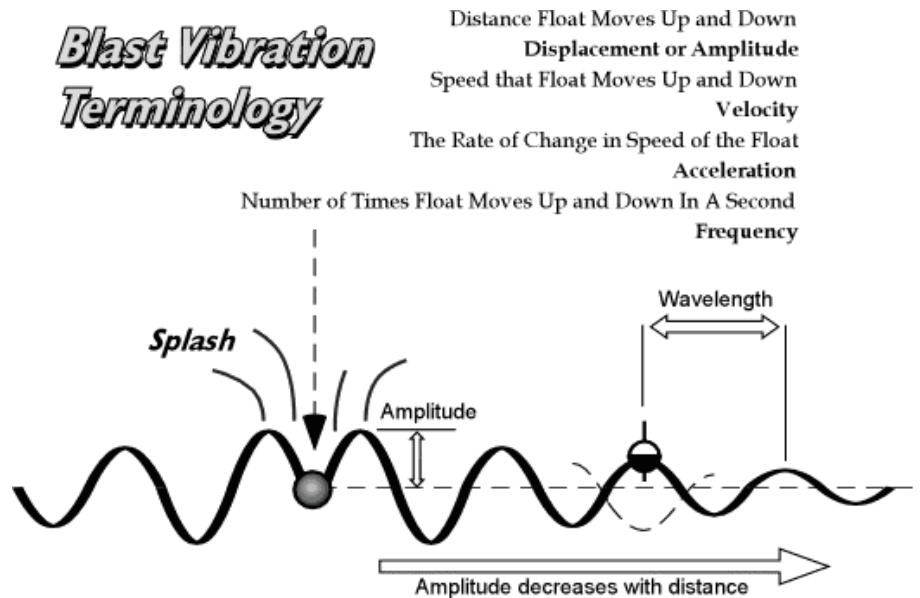


Figure A2.4 – Schematic diagram of vibration terminology

With ground vibration, the motion of the surface of the ground can be measured by coupling a suitable instrument directly to the surface.

Early researchers into ground vibration discovered a closer relationship between velocity of the ground surface and the response of structures than either displacement or acceleration. Measurement of velocity of the motion of the surface of the ground near where it enters a building has become the standard by which ground vibration is measured and regulated.

Ground vibration is measured with a blasting seismograph and is commonly expressed in terms of Peak Particle Velocity and measured in terms of millimetres per second (mm/s). To define the motion in three dimensions, it is necessary to use three transducers to measure the vibration in three mutually perpendicular directions and then determine a Peak Particle Velocity or Peak Vector Sum, which is the instantaneous maximum vector of the three individual measurements:

$$\text{ie. PPV (PVS)} = \sqrt{v_t^2 + v_l^2 + v_v^2}$$

Rather than being the simple wave type in the pond illustration, the ground vibrations are more complicated seismic events. The blast vibration consists of the different waves from each hole in the blast with propagation controlled by the physical and structural properties of the ground through which it travels.

The ground vibration wave motion consists of different kinds of waves:

- Compressional (or P) waves.
- Shear (or S or secondary) waves.
- Rayleigh (or R) waves.

The Compressional or 'P' wave is the fastest wave through the ground. The simplest illustration of the motion of the particles within the 'P' wave is to consider a long steel rod struck on the end. The particles of the rod move to and fro as the compressive pulse travels along the rod, ie. the particles in the wave move in the same direction as the propagation of the wave.

The 'P' wave moves radially from the blasthole in all directions at velocities characteristic of the material being travelled through (approximately 2200 m/s). The wave motion of 'P' waves is illustrated in **Figures A2.5** and **A2.6**.

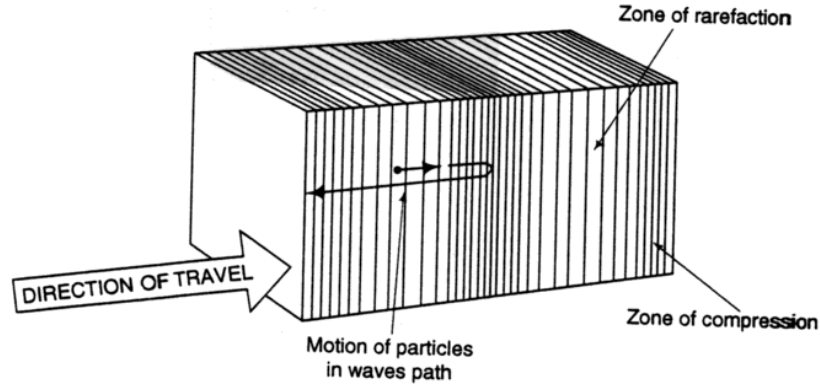


Figure A2.5 – Compressional ('P') wave particle motion

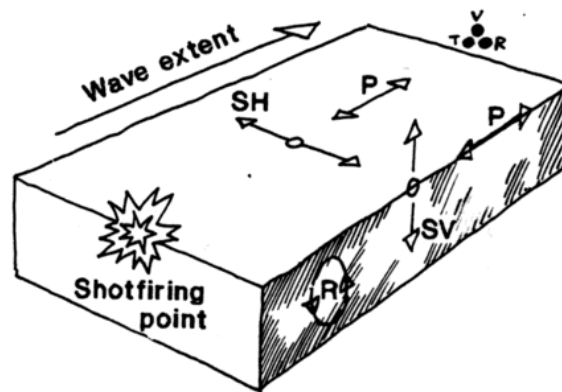


Figure A2.6 – Seismic wave motion

The Shear or 'S' wave travels at approximately 1200 m/s (50% to 60% of the velocity of the 'P' wave). The motion of the particles within the wave can be illustrated by shaking a rope at one end. The wave travels along the rope, but the particles within the wave move at right angles to the direction of motion of the wave. The wave motion of 'S' waves is illustrated in **Figures A2.6** and **A2.7**. The 'P' waves and 'S' waves are sometimes referred to as "body waves" because they travel through the body of the rock in three dimensions.

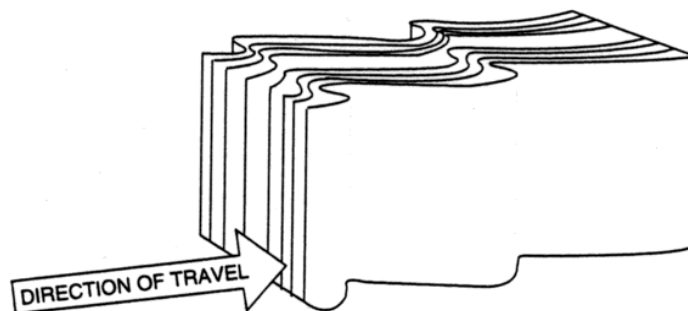


Figure A2.7 – Shear ('S') wave particle motion

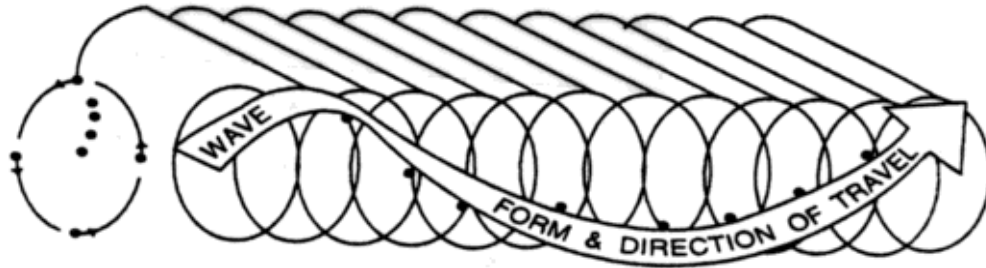


Figure A2.8 – Rayleigh ('R') wave particle motion

The Raleigh or 'R' wave is a surface wave, which fades rapidly with depth and propagates more slowly (750 m/s) than the other two waves. The particles within the wave move elliptically in a vertical plane in the same direction as the direction of propagation. At the surface the motion is retrograde to the movement of the wave, similar to waves on the ocean. The wave motion of the 'R' waves is illustrated in **Figures A2.6 and A2.8**.

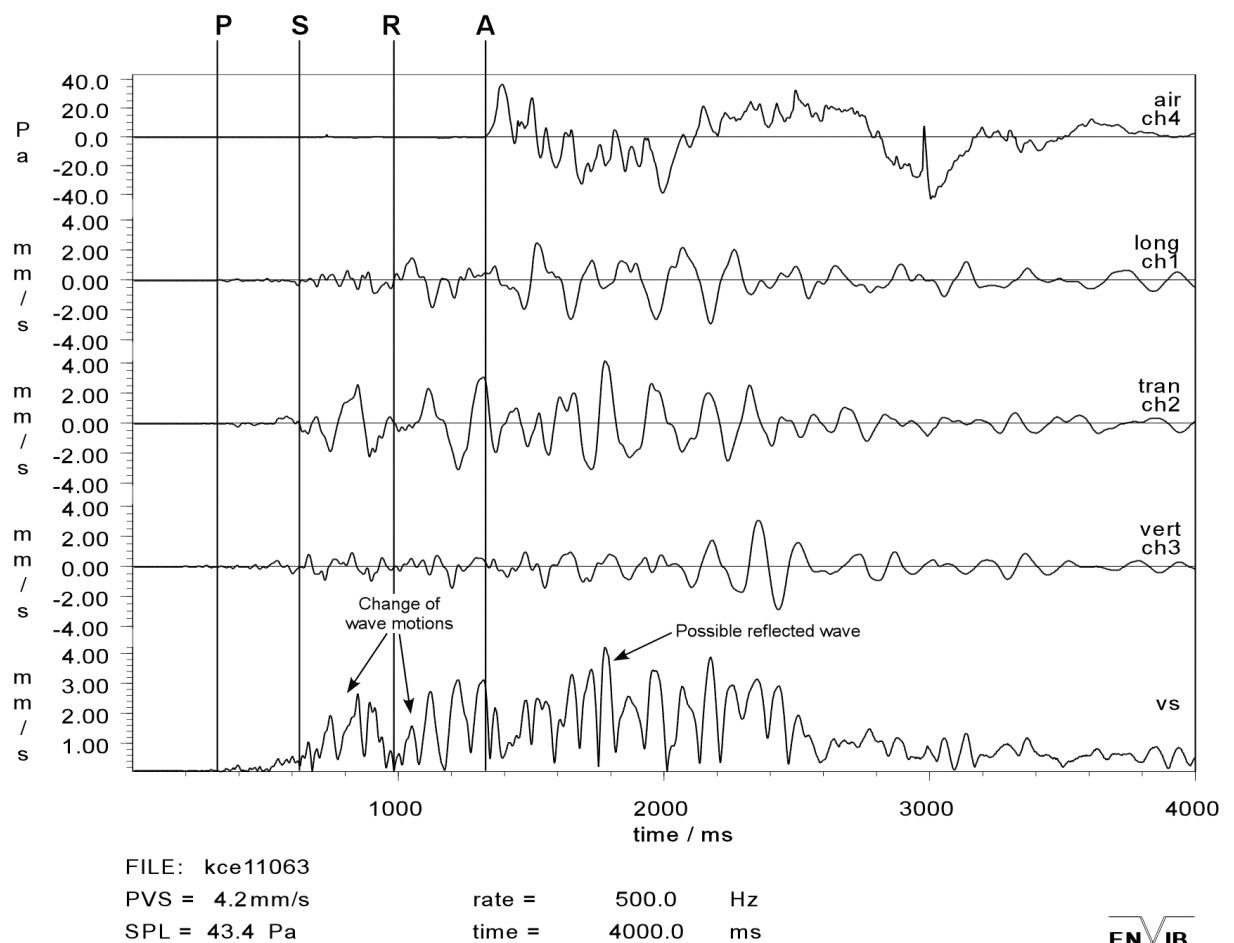


Figure A2.9 – Typical ground vibration wavetrace at Echo monitor showing 'P', 'S' 'R' and 'A' wave arrivals

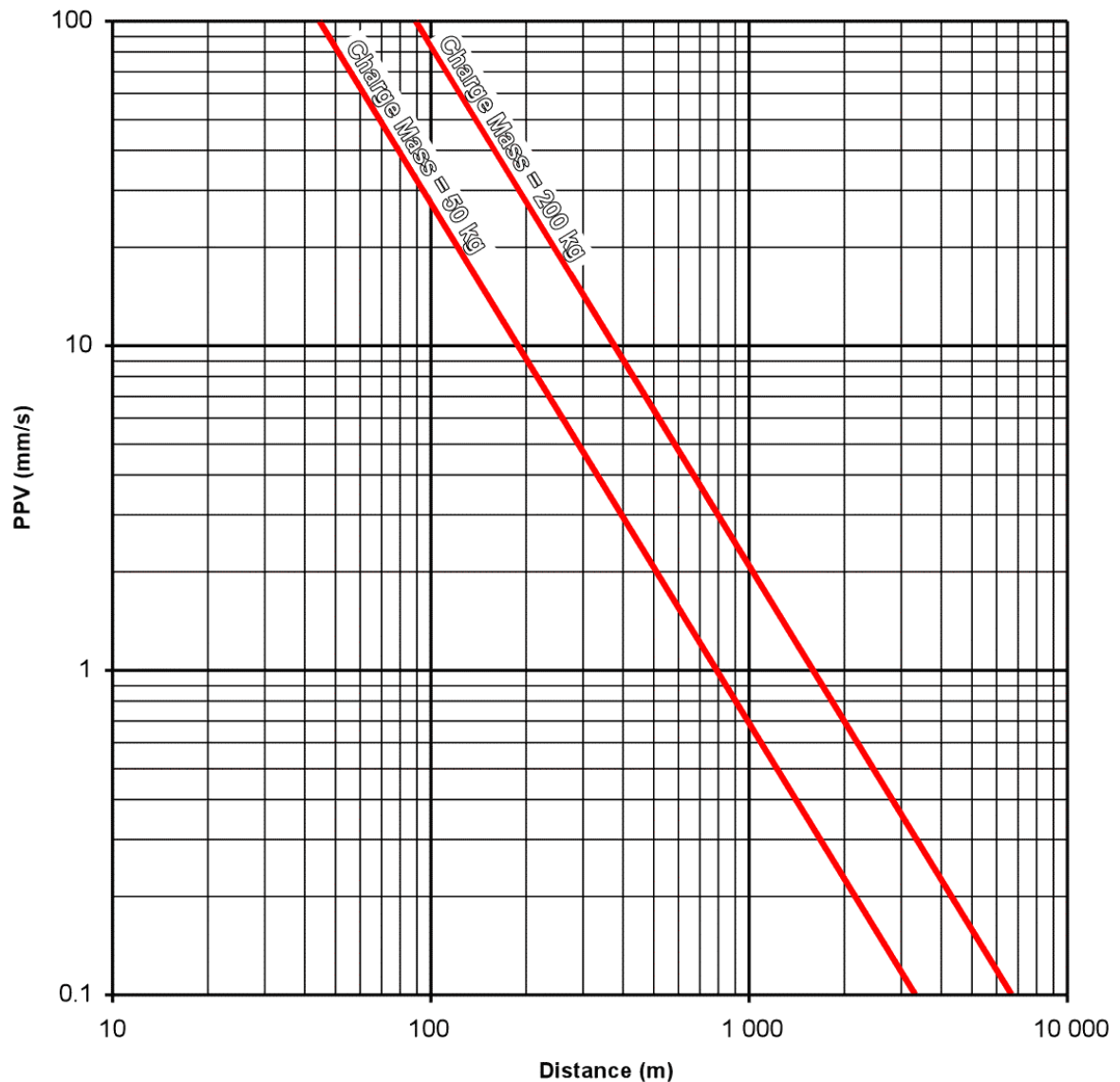


Figure A2.10 – The relationship between charge mass, distance and PPV

The manner in which ground vibration reduces with distance is demonstrated in **Figure A2.10**. This shows typical maximum vibration levels that results from a large blast (many holes) with a maximum charge mass of 50 kg and 200 kg/hole and an attenuation rate determined for the Echo monitor for Chaffers area blasts. The vibration levels from the Stores area blasts are about one third of the maximum vibration levels shown. The vibration measured at many locations for the same blast may show a considerable variation from the maximum lines shown in **Figure A2.10**. Variations in vibration levels ranging from one fifth of the maximum to the maximum are common.

In general terms, ground vibration increases with increased charge mass and reduces with distance. The relationships between charge mass, distance and vibration can be determined from analysis and then used in predictive formula to limit and control the ground vibration.

A2.2 Air Vibration

When air vibration is within the range of hearing it is called 'sound'. When its frequency is below the range of hearing, it is generally referred to as 'concussion' or 'airblast'.

Air vibration from blasting is measured with an air vibration meter, which meets the requirements of Australian Standard 2187.2-1993 and is expressed in terms of decibels (linear) or dBL.

Air vibration radiates outwards from the blast site in a similar manner to ground vibration, but at a slower rate (see **Figure A2.9**). The time between the arrival of the ground vibration and air vibration depends on the distance from the blast. At one kilometre, the air vibration arrives approximately 2.5 seconds after the ground vibration. People may experience the blast as two separate events, ie. separate air and ground vibrations.

Air vibration also attenuates with distance. A typical reduction of airblast with distance (attenuation) is shown in **Figure A2.11**. The ground vibration attenuates to below perception levels faster than air vibration, at distances further than about one kilometre from the blast, people may only be aware of the air vibration

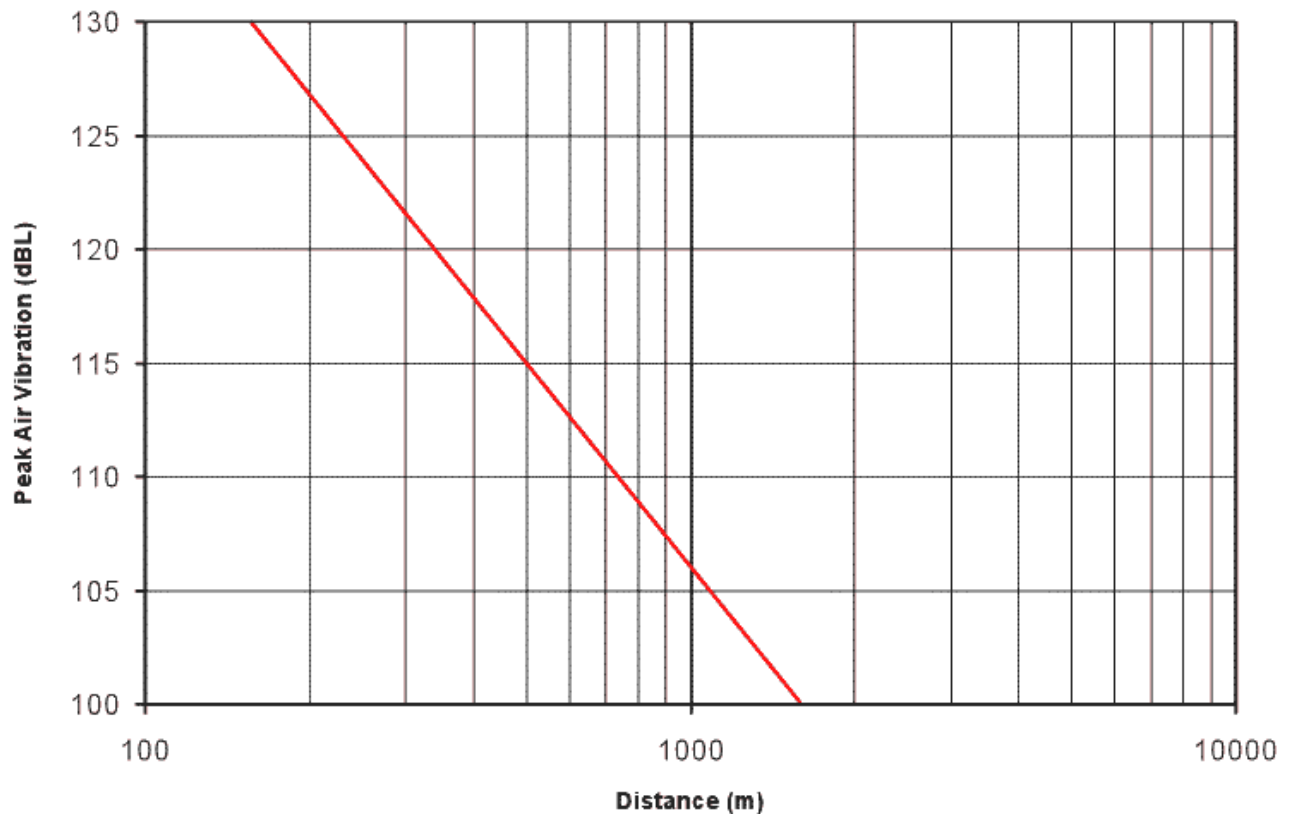


Figure A2.11 – Basic air vibration emission showing face effect and attenuation

A2.2.1 Shielding Effect of the Perimeter Bunding

The peak airblast levels result from blasts at the surface where there is no shielding afforded by the perimeter bunding, eg. the second blast in the current Chaffers area series of blasts resulted in an airblast level of 126.7 dBL at Echo monitoring station at 462 metres and was unshielded, compared to 115 dBL at 395 metres from a nearby blast shielded by the environmental noise bund.

To demonstrate the effect of shielding, Terrock has developed the following approach. **Figure A2.12** demonstrates terminology and **Figure A2.13** shows the shielding relationship that has been determined over many years of analysing airblast.

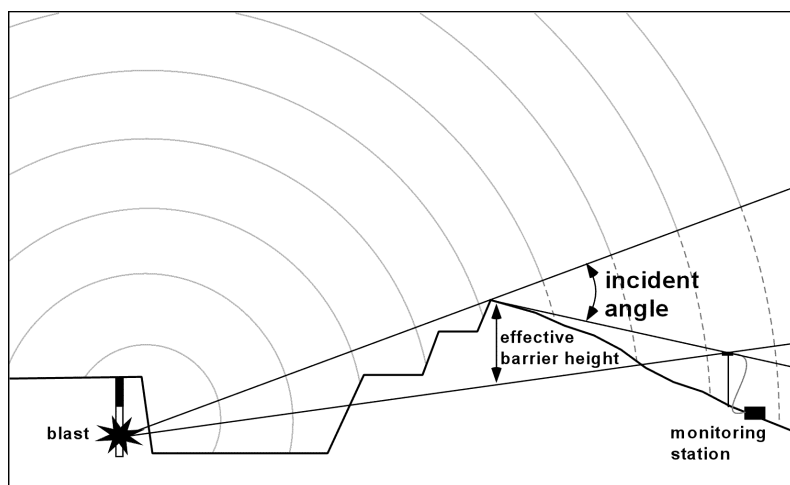


Figure A2.12 – Shielding terminology

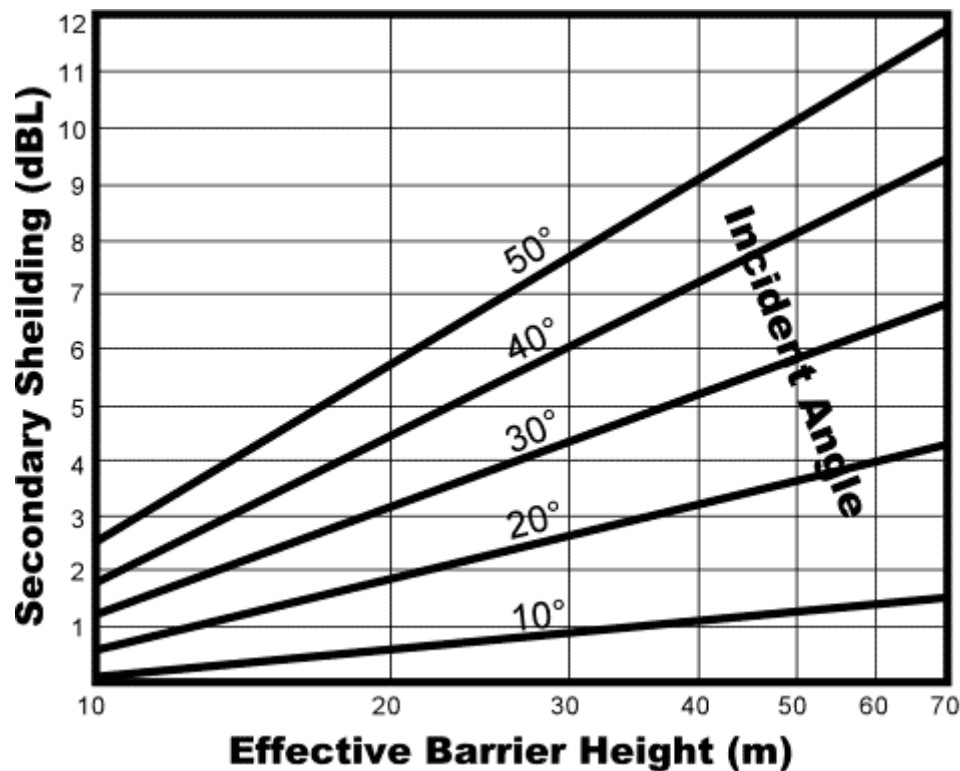


Figure A2.13 – Secondary shielding relationships

A section through the 30 metre high environmental noise bund is shown in **Figure A2.14**. Depending on how close the blast is to the bund and how far from the bund to the receptor point, the incident angle varies from 20° to 40° and the effective barrier height is about 35 metres. The range of shielding afforded by the bunding for surface blasts is estimated to be 2 to 7 dBL.

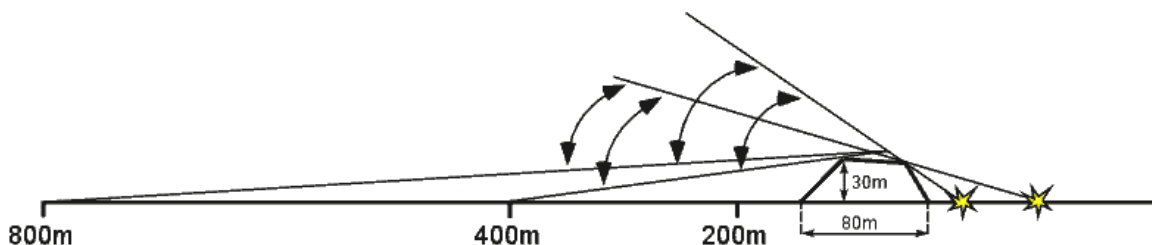


Figure A2.14 – Cross-section of a 30 metre bund

However, the effects of shielding are reduced as the distance from the blast increases because of flattening of the incident angle. The incident angle is also decreased as the receptor point moves around from the perpendicular to the bund. For instance, the airblast levels at the Charlie monitoring station are comparatively high for most blasts because of a low incident angle, even though the effective barrier height remains constant.

The effect of shielding is greater as the blasts are conducted lower in the pit because the incident angle and effective barrier height both increase. From our shielding model, blasts 30 metres deep at the extraction limit would be shielded by up to 1-2 dBL at receptors 400 metres from the blast.

A2.2.2 Meteorological Effects

Atmospheric conditions (meteorological reinforcement) and the degree of shielding (topographical shielding) can influence the level of air vibration resulting in the area surrounding a blast. Atmospheric conditions can, on occasions, concentrate or focus air vibration in certain directions and distances from the blast. Weather conditions that include an 'inversion' or a layer of warm air between colder air layers, such as exists on smog pollution days, can cause an increase of up to 10 or more decibels at distances from 2-5 km from the blast. The reinforcing mechanism is demonstrated in **Figure A2.15**.

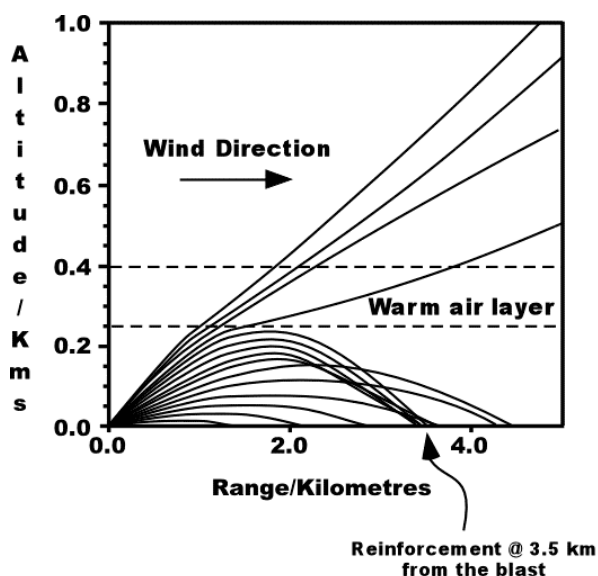


Figure A2.15 – Combined effect of wind and temperature inversion on sound rays causing surface reinforcement

Similar effects may be caused by increasing wind speed with altitude, especially when accompanied with a change of wind direction or wind shear. For meteorology to have a significant influence on air vibration levels, the inversion layer or wind shear must be at levels less than about 200-250 metres above the blast. The prediction of meteorological conditions requires accurate local data that is not freely available for use in adjusting blasting times to avoid reinforcements occurring. The practical effect of meteorological reinforcement is that, on occasions, blasts may be noticed in locations distant from the operation where they are normally imperceptible. Elevated airblast levels due to meteorology are usually below regulatory limits because at the distance from the blast at which they characteristically occur (>2 km), the basic emission levels are low following natural attenuation.

The wind also plays a significant part in air vibration measurement and interpretation. The air vibration meter contains a precision microphone with a low frequency response. The air vibration is measured by electrical signals generated by the response of the diaphragm of the microphone to changes of pressured caused by the Compressional wave. Wind also results in changes of pressure on the diaphragm of the microphone.

The change of pressure due to wind velocity can be determined from:

$$P = 0.6V^2$$

where: V = gust wind velocity (m/s)
 P = dynamic wind pressure (Pa)

A comparison of the pressure due to wind velocity expressed in Pa (AS1170.2-1989, SAA Loading Code Part 2: Windloads) and the decibel equivalent are listed in **Table A2.1**.

Table A2.1 - A comparison of the pressure due to wind velocity expressed in Pa and decibel equivalent

Wind Velocity		Beaufort Description of Wind and Observed Effects	Pressure	
m/s	km/hr		Pa	dBL
1.0	2.6	Light air; direction shown by smoke drift	0.6	89.5
1.7-3.0	6.0-11.0	Light breeze; wind felt on face	1.73-5.4	99.0-109.0
4.3	15.6	Gentle breeze; leaves, small twigs in constant motion	11.2	115.0
5.0	18.0		15	117.5
5.8	20.8	Moderate breeze; raises dust and loose paper	20	120.0
10.0	36.-	Fresh breeze; leafy trees sway	60	129.5

Wind described as a light breeze can cause a pressure change equivalent to air vibration of 109 dBL. A gentle breeze can cause a pressure change equivalent to the environmental guideline of 115 dBL. The pressure changes equivalent to the environmental guideline of 120 dBL are caused by a moderate breeze that begins to raise dust and loose paper. The slightest breeze can cause pressure changes that are recorded on the signal trace. The signals due to wind may overwhelm the signals from the blast, so specialist techniques have been developed to distinguish between the two events.

For those who are unfamiliar with sound measurement, it is hoped that the following explanation will be of assistance. The difference in air pressure between sound pressure levels that are barely noticeable and those that will damage buildings is very large. For this reason, sound and airblast levels are measured on a decibel scale, which is logarithmic. On this scale, an increase of 6 decibels represents a doubling of the sound pressure levels, expressed as Pascals.

Air vibration measurement is further complicated by the use of the decibel A (dBA) scale for audible community noise level measurement and the use of the decibel (linear peak) or dBL (peak) scale for the measurement of air vibration from blasting. It is necessary to measure the air vibration from blasting on the dBL (Peak) scale because it has a considerable sub-audible component, which can affect houses and other buildings.

As a comparison between the two systems, if a Precision Sound Level Meter which was set to measure air vibration from blasting measured 115 dBL (Peak), an identical Precision Sound Level Meter set to measure community noise on the dBA scale could measure approximately 90 dBA for the same blast.

Air vibration is controlled by proper blast design and implementation to confine the energy of the explosive within the rock mass until the fragmentation and rock movement is under way. Appropriate stemming height, stemming material and burden for the charge mass of explosive in the blasthole are important for controlling airblast.

A2.3 Ground Vibration Limits

A2.3.1 Structural Damage Limits

The vibration from open pit blasting is managed in accordance with the Australian Standard levels specified in the KCGM Noise and Vibration Monitoring and Management Programme. The vibration from the Super Pit is limited to 10 mm/s at a residence or other vibration sensitive locations. The source of the 10 mm/s is the recommended maximum peak particle velocity from Table J1 of Australian Standard 2187.2-1993, Footnote 3 of the Table, which states:

'The peak particle velocities in the Table have been selected taking into consideration both human discomfort and structural integrity together with the effect on sensitive equipment located within buildings.'

Footnote 2 states:

'In a specific instance, where substantiated by careful investigation, a value of peak particle velocity other than that recommended in the Table may be used.'

The recommended limit of Australian Standard 2187.2-1993 of 10 mm/s includes a consideration of human response. In purely structural integrity terms, British Standard 7385: Part 2: 1993 provides guideline limits for the prevention of cosmetic damage, ie. the formation of hairline cracks on dry wall surfaces, the growth of existing cracks in plaster or dry wall surfaces, or the formation of hairline cracks in mortar joints of masonry construction from vibration.

The guideline limits are based on the frequency contained in the vibration in recognition that ground vibration at or near the natural frequency of the building may induce a resonant response in a structure and a reduced limit is appropriate in this circumstance.

The transient vibration guide values are shown in **Table A2.4** and **Figure A2.16**.

Table A2.4 – Transient vibration guide values for cosmetic damage (British Standard 7385:1993)

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

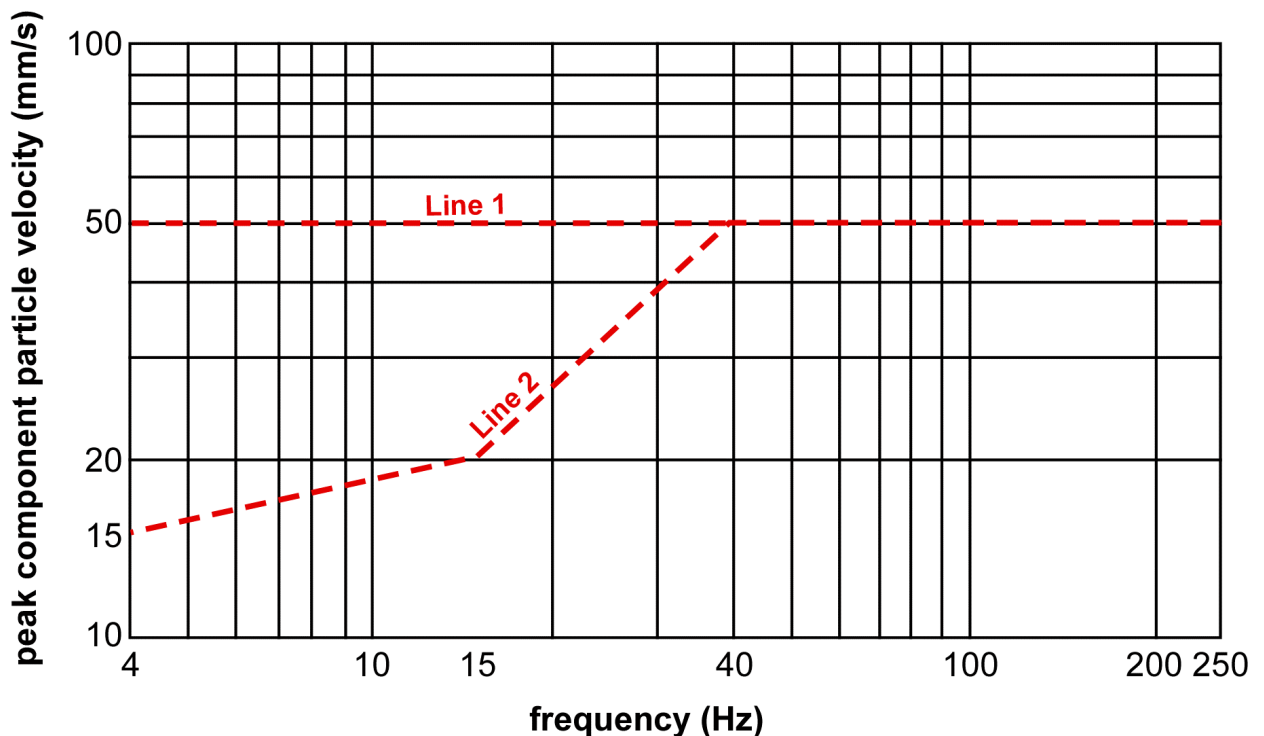


Figure A2.16 - Transient vibration guide values for cosmetic damage (British Standard 7386:1993)

The following paragraphs are included in the British Standard:

7.5.1 Fatigue Considerations

There is little probability of fatigue damage occurring in residential building structures due to either blasting, normal construction activities or vibration generated by either road or rail traffic. The increase of the component stress levels due to imposed vibration is relatively nominal and the number of cycles applied at a repeated high level of vibration is relatively low. Non-structural components (such as plaster) should incur dynamic stresses which are typically well below, ie. only 5%, of component yield and ultimate strengths. Thus unless calculation indicates that the magnitude and number of load reversals is significant (in respect of the fatigue life of building materials) then the guide values in Table 1 should not be reduced from fatigue considerations.

7.5.2 Important Buildings

Important buildings which are difficult to repair may require special consideration on a case-by-case basis. A building of historical value should not (unless it is structurally unsound) be assumed to be more sensitive.'

The important points made in these sections of the British Standard are:

- If vibration results in dynamic stresses that are relatively low compared to the ultimate yield strength of the materials then fatigue due to the cumulative effect of numbers of load reversals does not warrant reduction in the guide values.
- No reduction in guide values should be made for important buildings unless they are structurally unsound.
- The peak particle velocity (peak vector particle velocity) is the maximum instantaneous vector sum of the three component velocities. The peak component particle velocity is, therefore, usually less than the peak vector particle velocity. The theoretical ratio of peak component particle velocity to peak vector particle velocity is in the range 0.58 to 1.0; in practice, the ratio is usually about 0.7, ie. a peak component particle velocity of 12.4 mm/s represents a peak vector particle velocity of about 17.7 mm/s.

A2.3.2 Airblast Damage Criteria

Australian Standard 2187.2-1993 recommends a maximum air vibration level of 133 dBL to prevent structural damage. Air vibration will not cause damage at levels below 133 dBL but the probability of damage increases as air vibration levels increase beyond 133 dBL. The size of a pane, the thickness and mounting of the glass are significant factors in resistance to air vibration. Large panes are more likely to be damaged at lower levels than small panes. Following the investigations of the USBM (Siskind et al 1980a), typical overpressure damage criteria is listed in **Table A2.5**.

Table A2.5 – Typical overpressure damage criteria

20,000 Pa - 180 dBL:	Possible structure damage.
7,100 Pa - 171 dBL:	General window breakage.
710 Pa - 151 dBL:	Occasional window breakage.
200 Pa - 140 dBL:	Long-term history of application as a safe project specification in the USA.
100 Pa - 134 dBL:	USBM recommendation following a study of large-scale surface mine blasting.
89 Pa - 133 dBL:	AS2187.2-1993 recommended limit to avoid structural damage.
20 Pa - 120 dBL:	AS2187.2-1993 recommended peak/ANZECC recommended peak.

A2.4 Human Response to Vibration

In society there is a wide variation in vibration tolerance, depending on social and cultural factors, psychological attitudes and an expected interference with privacy, an increase in the awareness of rights of the individual, and increasingly complex political agendas.

Some people complain regarding vibration at levels slightly above perception levels, ie. as soon as they feel it. Others become accustomed to and tolerate relatively high levels of vibration, eg. residents in close proximity to railway lines and freeways. Some of the reactions to vibration include a 'fright' factor or being startled by a sudden vibration event.

Contributing factors to the human perception of vibration are the length of time of the vibration event, the frequency spectrum of the vibration, the number of occurrences per day, the time they occur and the magnitude (displacement, velocity or acceleration of the vibration).

The perception of blast vibration is further complicated by the presence of ground vibration and air vibration, which separate with distance because of the different propagation velocities.

Both air and ground vibration are commonly perceived by secondary noise, such as rattling of dishes, windows or sliding doors, and without monitoring it may not be possible to recognise whether air or ground vibration is being responsible.

Attempts have been made to qualify human sensitivity to vibration and typical human response graphs are shown in **Figures A2.17a** and **A2.17b**. The graphs are based on the studies listed in **Figure A2.17b**. The shortest vibration duration is 5 seconds, which is a longer period than most blasting events. The PPV figure represents the vibration in the structure where it enters the human body (usually the floor).

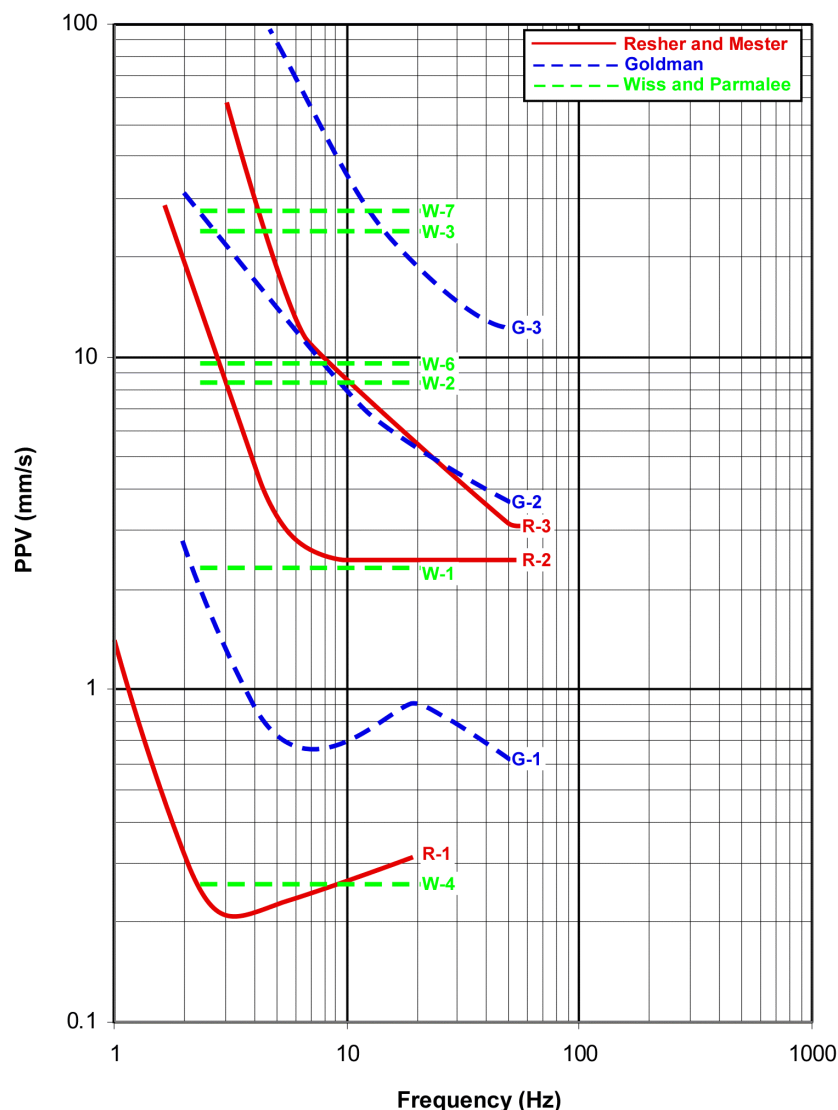


Figure A2.17a – Human response to steady-state and transient vibrations compared to the environmental limits

Authors	Vibration duration, sec	Curve representations, response descriptors, and curve label for data plotted in figure 61
Goldman (18): Various body positions, 5 sources	5	Mean values of subject response:
Do	5	Perceivable (curve G-1).
Do	5	Unpleasant (curve G-2).
		Intolerable (curve G-3).
Reiher and Meister (40): Standing with vertical vibration	300	Thresholds:
Do	300	Barely noticeable (curve R-1).
Do	300	Objectionable (curve R-2).
		Uncomfortable (curve R-3).
Wiss and Parmalee (58): Standing with vertical vibration	5	Mean values of subject response:
Do ¹	5	Barely perceptible (curve W-1).
		Distinctly perceptible (curve W-2).
Do ¹	5	Strongly perceptible (curve W-3).
		Thresholds:
Do ¹	5	Barely perceptible (curve W-4).
Do ²	5	Distinctly perceptible (curve W-5).
Do ²	5	Strongly perceptible (curve W-6).
Do ²	5	Severe (curve W-7).

¹ Transient with 1 pct damping, 5-sec duration is maximum.

² Zero damping.

Figure A2.17b – Studies of human response to vibration

In our experience, vibration is perceptible at between 0.2 mm/s and 0.5 mm/s, depending on the activities of the receiver at the time, whether indoors or outside, and the frequency and duration of the vibration. Some people do become concerned when ground vibration exceeds 3-5 mm/s, which is approximately in accordance with curve G2 (unpleasant) and curve W2 (mean of distinctly perceptible).

A number of Standards have attempted to address the issue of whole body response to vibration in buildings. The vibration is measured at the entry of the vibration to the body, which is usually the floor. A typical set of guide vibration levels tolerated by humans in building is given in **Table A2.6** from the American National Standards Institution (ANSI) S3.18-1979.

Table A2.6 – Peak vibration levels tolerated by humans in buildings (ANSI S3.18-1979)

	Number of Events Per Day		
	1	12	26
	PVL (mm/s)	PVL (mm/s)	PVL (mm/s)
Critical Structure (eg. hospital):	0.13	0.07	0.05
Residence (night):	0.20	0.10	0.7
Residence (day):	12.5	6.3	4.3
Office or Workshop:	18.0	9.0	6.0

The guidance vibration levels are for 8 Hz to 80 Hz (vertical plus horizontal motions) for events lasting up to one second.

The Australian and New Zealand Environment Conservation Council (ANZECC) guidelines to minimise the annoyance due to blasting overpressure and ground vibration are another example of vibration limits based on human response criteria. For blasts between 9:00 am and 5:00 pm Monday to Saturday, the guidelines recommend a maximum ground vibration level of 5 mm/s (which may be exceeded on 5% of occasions in a twelve month period to a maximum of 10 mm/s). The frequency component is not considered. Current ground vibration from blasting in the Super Pit complies with the ANZECC guidelines.

The ANZECC ground vibration limit of 5 mm/s would approximate to the 12.5 mm/s ANSI day time residential limit, allowing for a 2.5 times structural magnification, which is within the range of magnifications expected on the floor of a building.

The aspects of vibration that are not considered in vibration studies are the audible structure borne noise due to structural adjustment or the audible response of loose objects in the building, such as dishes on a sink. These can be the most strongly perceptible of the effects of vibration to people in buildings and can account for a considerable 'startling factor' if no other warning has been given that a blast was imminent. The secondary audible effects can be more perceptible than the vibration itself.

A2.5 KCGM Operational Limits

The current vibration standards and limits are specified in the KCGM Noise and Vibration Monitoring and Management Programme:

A2.5.1 Ground vibration

Ground vibration from open pit blasting will not exceed the Australian Standard of 10 mm/s at houses. No more than 1 in 10 consecutive blasts will exceed 5 mm/s at houses.

A2.5.2 Airblast Overpressure

Between 07:00 and 18:00 hours Monday to Saturday:

- Airblast overpressure from blasting will not exceed 125 dBL (linear peak) at houses.
- No more than 1 in 10 consecutive blasts will exceed 120 dBL (linear peak) at houses.

Between 07:00 and 18:00 hours on a Sunday or public holiday:

- Airblast overpressure from blasting will not exceed 120 dBL (linear peak) at houses.
- No more than 1 in 10 consecutive blasts will exceed 115 dBL (linear peak) at houses.

The standards and limits at the Super Pit are a compromise between human response criteria and structural damage limit criteria. Buildings exposed to the levels of vibration permitted by the operating condition limits will not be damaged by the vibration from blasting.

APPENDIX 3A – WORST-CASE GROUND VIBRATION ASSESSMENT



APPENDIX 3B – AVERAGE GROUND VIBRATION ASSESSMENT



APPENDIX 4A – WORST-CASE AIRBLAST ASSESSMENT



APPENDIX 4B – AVERAGE AIRBLAST ASSESSMENT

