Appendix J3: Blasting and Vibration Study

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16th March 2017

Dear Chiara,

EVALUATION OF THE POSSIBLE IMPACT OF DRILL AND BLAST OPERATIONS ON THE PROPOSED NEW KATHU CEMETERY.

1. Background.
A new cemetery is being planned for the town of Kathu. The proposed location is on the north side of the N14 at a point approximately 13 kilometres south of the town of Kathu (Appendix 1).

There is extensive existing mining activity in the vicinity of this location. The Sishen and Khumani operations are located to the north-west and west and two small open pit operations are found to the north-west and south-west of the proposed new Kathu Cemetery. The areas to the north-east, east and south-east are undeveloped.

When drilling and blasting takes place, there may be a number of blasting related disturbances that impact on the surrounding areas in the vicinity of the operation. When blasts are set off ground vibration and air blast disturbances occur, which diminish in intensity with increase in distance from the source. On occasion, fly rock, after blast fumes and dust may occur. These disturbances occur unexpectedly and for this reason may attract unwelcome attention.

The aim of this report is to assess the possible impact of the drill and blast operation on the proposed new cemetery location.

2. Proposed New Cemetery Site and Existing Mining Operation.
The proposed new cemetery location and the general area around this are shown in the attached Google image (Appendix 1). The positions of the operating mines can clearly be seen.

The distances from the proposed cemetery to the various existing mining operations were determined using Google Earth. These distances are required to assist with the prediction of ground vibration and airblast levels. The distances are as follows:

Cemetery NW corner	Sishen mine	3,620m
Cemetery NW corner	Khumani	2,540m
Cemetery NW corner	Pit to the NW	1,865m
Cemetery SW corner	Pit to the SW	2,540m

The closest infrastructure that will be affected by blasting at the various operations includes the tar road and the railway line. The impact on this infrastructure is not considered in this report.

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3. Objective.
This report considers the possible influence of the blasting operations on the location of the cemetery.

The following aspects of the blasting operation were assessed:

3.1 Blast design and general safe blasting practice.
3.2 Ground vibration – predicted levels.
3.3 Airblast – predicted levels.
3.4 Side effects such as fly rock, after blast fumes and dust.

3.1 Blast Design.
A number of blast designs for different rock types were provided by one of the local operating mines. The design for Calcrete blasting resulted in the highest powder factor. This design was therefore modelled to assess various firing sequences that increased the number of holes firing together and the resultant combined charge mass per delay. Based on these figures the peak particle velocities were calculated at various distances. These predictions can be compared to recognised standards such as the United States Bureau of Mines Standard (USBM RI 8507) and / or the Deutsches Institut für Normung (DIN standard) to ensure compliance (see Appendix 2 for a summary of these standards).

3.2 Ground Vibration.
Ground vibration and air blast can attract the most attention from people. Ground vibration disturbances need to be measured and quantified to ensure compliance with recognised and accepted industry standards.

Factors Affecting Ground Vibration and Prediction of Ground Vibration Levels.
Ground vibrations occur as a consequence of blasting activity. The intensity of the vibrations depends on a number of factors some of which can be managed and controlled to help reduce the levels.

The two principal factors that control vibration levels are distance and charge weight. Vibration energy is attenuated by the rock mass so normally lower amplitudes are experienced further from a blast. Vibration levels will increase as the charge weight increases. The larger the charge mass the higher the amplitude of the vibration. The charge weight can be controlled by reducing the blasthole diameter or limiting the number of holes that fire at an instant in time.

Vibration Control. Effective vibration control can be exercised by making use of a propagation law developed by the US Bureau of Mines, which relates peak particle velocity (vibration), charge weight and distance. This is referred to as the “Scaled Distance Relationship” which takes the following form:

$$Sd = D/\sqrt{E}$$

and

$$PPV = a(Sd)^{-n}$$

Where

Sd = Scaled distance. Sd should be greater than or equal to 31 where no monitoring is carried out.

PPV = Peak Particle Velocity (mm/sec).

D = Distance to property of concern (m).

E = Mass of explosive per delay (kg).

a = Site specific constant, which is a function of the rock mass.

n = Site specific constant, which is a function of the rock mass.

This method provides an estimate only, since it assumes site-specific constants, which differ from site to site depending on the rock types. In the absence of site-specific information, a value of 1143 for "a" and a value of –1.6 for "n" can be used. Calculated values using these constants are usually conservative but provide a useful starting point.

The maximum allowable ground vibration amplitudes are frequency dependant with higher frequencies allowing higher peak amplitudes (Graph 1, Appendix 2). In general, at lower frequencies, the ground vibration should not exceed 12.7 mm/sec at houses, but at higher frequencies, the limit can increase to 50 mm/sec. Suggested maximum levels for peak particle velocity are summarized in the table below, which is included for reference. Please note the paragraph after the table which is related to the possible impact on gravestones.

Nature of structure	**PPV in mm/sec**
Heavily reinforced concrete structures.	120
Property owned by concern performing blasting. This could include buildings owned by the mine.	84
Private property where maximum level of public concern is taken into account. This would include private property, schools, churches etc.	12
National roads / Tar roads.	150
Steel pipelines.	50
Green Concrete i.e. aged for less than 3 days.	5
Concrete > 10 days.	20

Findings published by the New York Department of Transportation (PIN X729. 77 – BIN 1-07569-9) relating to the potential impact of blasting on an historic cemetery found that gravestones (the above ground elements) would typically have a maximum allowable PPV vibration criteria of 2.0 in/sec (50.8 mm/sec). Because of the historic status of the cemetery the PPV criteria was limited to 0.5 in/sec (12.7 mm/sec) and a maximum vertical and horizontal movement of 0.25 inch (6.35mm). The potential impact at the proposed Kathu cemetery is below these levels.

Human Response.
Human beings are easily disturbed at low levels of vibration. Levels of 0.76 to 2.54 mm/sec are quite perceptible, but the probability of damage is almost non-existent. Levels between 2.54 and 7.62 can be disturbing and levels above 7.62 can be very unpleasant depending on the sensitivity of individuals.

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Human perception is also affected by frequency. The approximate human response curves are combined with the USBM limiting curve for damage (Graph 2, Appendix 2). These curves slope in opposite directions. In other words, humans are more tolerant to low frequency vibrations.

To avoid damage to buildings the USBM limiting curve should be applied. To avoid constant complaints from residents, the vibration should be kept below the unpleasant curve and definitely below the intolerable curve.

Vibration Levels – Predictions.
Drill and blast parameters were provided for four different geological rock types viz. Calcrete, Bif, Ore and Quartzite. The modelling exercise used the blast parameters provided for Calcrete as blasting this material resulted in the highest powder factor and consequently the greatest explosive mass per bench blasted.

The number of holes firing together (and hence the charge mass) was progressively increased from 2 to 10 holes to determine the effect on the PPV levels at various distances. A 311mm diameter hole drilled to a depth of 12.5m on burden and spacing dimensions of 6.5m by 7.0m was used. A bulk explosive with an average in hole density of 1.06 was used in the calculation. This results in a powder factor of 0.90 kgs/cubic meter for the calcrete blast design. This is the worst case scenario. The two small pits will in all probability use smaller diameter holes and therefore smaller charge masses per hole.

In the data table the vibration levels at various distances from the blasting source are shown. The distances from the various pits to the cemetery are given below so that the possible influence of blasting at the cemetery location can be determined.

Cemetery NW corner	Sishen mine	3,620m
Cemetery NW corner	Khumani	2,540m
Cemetery NW corner	Pit to the NW	1,865m
Cemetery SW corner	Pit to the SW	2,540m

The following ground vibration levels were predicted:

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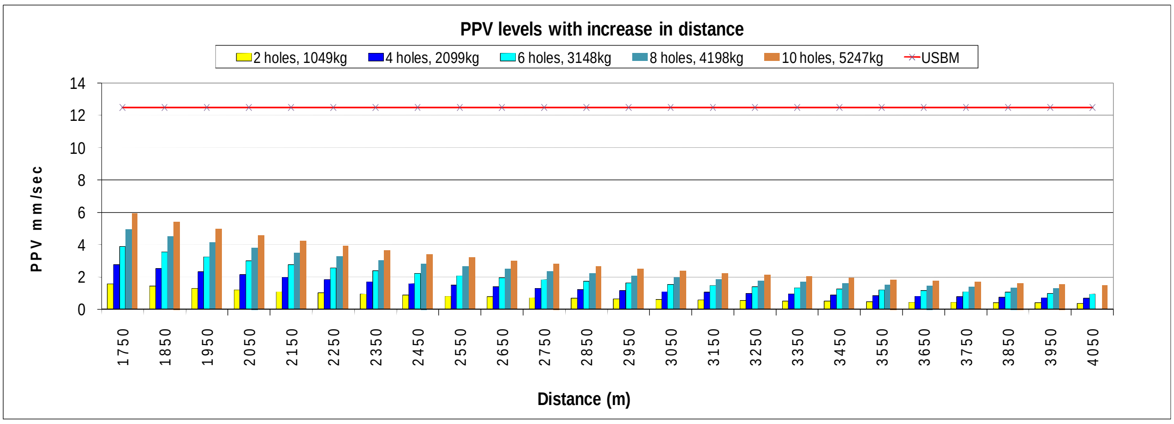
VIBRATION	Kathu Cem	Kathu Cem	Kathu Cem	Kathu Cem	Kathu Cem
Holes Detonated Per Delay >>>	2	4	6	8	10
Combined charge mass firing >>>	1049	2099	3148	4198	5247
Distance increment in metres v	2 holes, 1049kg	4 holes, 2099kg	6 holes, 3148kg	8 holes, 4198kg	10 holes, 5247kg
100	Calcrete	Calcrete	Calcrete	Calcrete	Calcrete
Distance (m)	PPV (mm/s)	PPV (mm/s)	PPV (mm/s)	PPV (mm/s)	PPV (mm/s)
1750	1.58	2.80	3.92	4.97	5.97
1850	1.44	2.56	3.57	4.53	5.45
1950	1.32	2.34	3.28	4.15	4.99
2050	1.22	2.16	3.02	3.83	4.60
2150	1.13	2.00	2.79	3.54	4.25
2250	1.05	1.85	2.59	3.28	3.94
2350	0.97	1.72	2.41	3.05	3.67
2450	0.91	1.61	2.25	2.85	3.43
2550	0.85	1.51	2.10	2.67	3.21
2650	0.80	1.41	1.98	2.50	3.01
2750	0.75	1.33	1.86	2.36	2.83
2850	0.71	1.25	1.75	2.22	2.67
2950	0.67	1.18	1.65	2.10	2.52
3050	0.63	1.12	1.57	1.99	2.39
3150	0.60	1.06	1.49	1.88	2.26
3250	0.57	1.01	1.41	1.79	2.15
3350	0.54	0.96	1.34	1.70	2.04
3450	0.52	0.91	1.28	1.62	1.95
3550	0.49	0.87	1.22	1.55	1.86
3650	0.47	0.83	1.16	1.48	1.78
3750	0.45	0.80	1.11	1.41	1.70
3850	0.43	0.76	1.07	1.35	1.63
3950	0.41	0.73	1.02	1.30	1.56
4050	0.40	0.70	0.98	1.24	1.50

The data tabulated above also shows how the PPV levels for a given charge mass attenuate rapidly with distance. This can be seen more clearly when the data is graphed - below. The PPV levels are well within accepted levels even when ten holes (5247kgs of explosive) are fired together.



In my experience the results obtained using the USBM formula with the given constants are conservative and the actual vibration levels are usually lower than those predicted. The geology in the area will control the attenuation of the shock waves.

3.3 Airblast

Airblast is frequently the main cause of blasting related complaints. Airblast is an atmospheric pressure wave consisting of high frequency sound that is audible and low frequency sound or concussion that is sub-audible and cannot be heard. Either or both of the sound waves can cause damage if the sound pressure is high enough (Konya).

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Airblast results from explosive gasses being vented to the atmosphere that results in an air pressure pulse. This occurs as a consequence of stemming ejections or hole blowouts, direct rock displacement through face ruptures or surface cratering, the use of high Velocity of Detonation (VOD) accessories that are left unconfined and / or uncovered (e.g. detonating cord on surface), by ground vibration or by various combinations of the above.

It is difficult to predict air blast levels with certainty due to unknown blast conditions as well as varying atmospheric conditions. However, airblast can be successfully contained below 130dB by precise control of the charging operation. Airblast amplitudes up to 135dB should not cause damage.

Suggested threshold limits for air blast (below) have been proposed by Personn et.al. 1994. The USBM recommended threshold for human irritation is 134dB.

120 dB	Threshold of pain for continuous sound
>130 dB	Resonant response of large surfaces (roofs, ceilings). Complaints start.
150 dB	Some windows break
170 dB	Most windows break
180 dB	Structural Damage

Airblast Prediction.
Given the variables associated with airblast any attempt to predict air blast levels can only be regarded as subjective. In my opinion good blast management coupled with the correct blast procedures will keep the airblast levels to acceptable limits. Blasts that have been correctly designed, laid out and executed should not result in excessive airblast.

There are a number of equations that can be used to try and predict airblast. Airblast is scaled according to the cube root of the charge weight:

$$K = D/W^{0.33}$$

The following equation can be used for the calculation of air blast:

$$L = 165 – 24 \text{ Log}_{10} (D/W^{0.33})$$

Where
- K = Scaled distance value.
- L = Airblast level (dB)
- D = Distance from source (m)
- W = Charge mass per delay (kg)

The air blast levels were calculated for the same charge masses as used for the prediction of ground vibrations. The airblast levels are given in the table below. The data is graphed against the Persson recommended limit.

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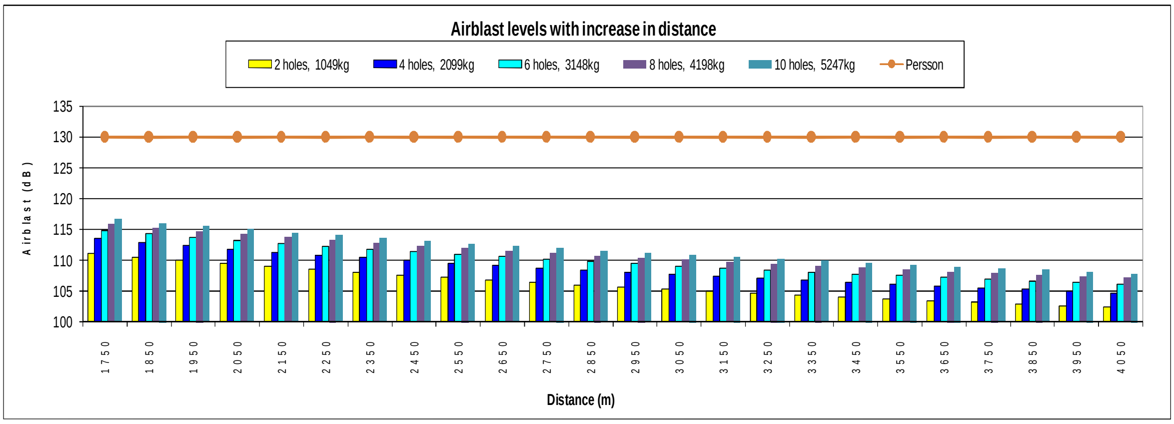
AIRBLAST					
Holes Detonated Per Delay >>>	2	4	6	8	10
Combined charge mass firing >>>	1049	2099	3148	4198	5247
Distance increment in metres	2 holes, 1049kg	4 holes, 2099kg	6 holes, 3148kg	8 holes, 4198kg	10 holes, 5247kg
100	Calcrete	Calcrete	Calcrete	Calcrete	Calcrete
Distance (m)	dB	dB	dB	dB	dB
1750	111	113	115	116	117
1850	111	113	114	115	116
1950	110	112	114	115	116
2050	109	112	113	114	115
2150	109	111	113	114	114
2250	108	111	112	113	114
2350	108	110	112	113	114
2450	108	110	111	112	113
2550	107	110	111	112	113
2650	107	109	111	112	112
2750	106	109	110	111	112
2850	106	108	110	111	112
2950	106	108	109	110	111
3050	105	108	109	110	111
3150	105	107	109	110	111
3250	105	107	108	109	110
3350	104	107	108	109	110
3450	104	106	108	109	110
3550	104	106	107	108	109
3650	103	106	107	108	109
3750	103	106	107	108	109
3850	103	105	107	108	108
3950	103	105	106	107	108
4050	102	105	106	107	108



The airblast levels at the cemetery location are all below the recommended Persson threshold limit. Damage to cemetery structures will not occur at these levels.

3.4 Side Effects - Fly Rock.

Side effects such as fly rock are undesirable and usually occur unexpectedly, sometimes for unknown reasons.Fly rock typically originates either from the free face or the surface of the blast or possibly from secondary blasting. The main causes are under burdened holes on the free face, geological discontinuities, poor blast timing leading to over confinement of holes and overcharged blastholes that result in cratering of the hole.

Fly rock will not pose a threat to the new cemetery as it is too far away from the existing mining operations.

Post Blast Fumes and Dust.

Explosives are formulated to be oxygen balanced to minimize fumes and optimize the energy output. Fumes such as carbon monoxide and oxides of nitrogen can be produced in the detonation process. Dust on the other hand is an inevitable consequence of blasting.

A number of factors can contribute to the creation of fumes. A number of these are mentioned below:

- Wind direction and conditions;
- Poor quality control and incorrect formulation;
- Excessively long sleep times (i.e. when the explosive is left in the blasthole for an extended period of time before being detonated);
- Damage to the explosive;
- Inadequate water resistance;
- Poor ground conditions;
- Premature loss of confinement;
- Inadequate priming; and
- Insufficient charge diameter.

It is difficult to ensure that post blast fumes never occur because some of the factors above are outside the blasters control.

Post blast fumes and dust will not pose a threat to the new cemetery as it is too far away from the existing mining operations.

4. Knowledge Gaps.
The prediction of the possible disturbance levels at the cemetery location is based on reasonable assumptions regarding the blast patterns to be drilled and blasted. Generally accepted equations and modeling methods were used to perform the calculations on which the predictions are based.

5. General Information and NEMA Regulations (2014).
The scope of this report was to identify the potential influence of blasting activity in the area on the proposed new cemetery location. No site investigation was carried out as the site is remote with no established infrastructure. The report focuses on:

- Prediction of ground vibration for increasing charge mass at various distances;
- Prediction of air blast as above; and
- Assessment of side effects such as fly rock, post blast fumes and dust.

My (alphabetical) customer base includes the following companies: Afridex (DRC), Anglo Platinum at various operations, Aquarius Platinum Marikana Mine, Bombela Consortium, Bulk Mining Explosives, Council for Geoscience, Enviro Blast, Exxaro, Gecamines (DRC), imPafa Technologies, Impala Platinum, Lonmin, Lyttelton Dolomite, Mashala Resources, Master Blaster, MCC Contracts Drilling and Blasting, Moolman Mining, Mubiji Mayi (DRC), Murray and Roberts, NuCoal, Pilanesberg Platinum Mine, Pretoria University, SLR Consulting (Africa), Shanduka Colliery, Tharisa Minerals, Total Coal, Tselentis Mining and Xstrata Coal and alloys.

This report was prepared by Erik Kohler, B.Sc. Geology (UCT). I operate independently or with associates on an as and when required basis. This allows the services and expertise of other professionals who offer specialised services and/or equipment for a specific need to be accessed. I have no vested interest in the projects that I am involved in other than to be compensated for the services that I render, which is a normal requirement.

NEMA Regulations (2014) - Appendix 6	**Relevant section in report**
Details of the specialist who prepared the report.	Section 5.
The expertise of that person to compile a specialist report including a curriculum vitae.	Section 5.
A declaration that the person is independent in a form as may be specified by the competent authority.	Section 5.
An indication of the scope of, and the purpose for which, the report was prepared.	Section 5.
The date and season of the site investigation and the relevance of the season to the outcome of the assessment.	N / A
A description of the methodology adopted in preparing the report or carrying out the specialised process.	Section 4.
The specific identified sensitivity of the site related to the activity and its associated structures and infrastructure.	Section 2.
An identification of any areas to be avoided, including buffers	Sections 3.2 and 3.3
A map superimposing the activity including the associated structures and infrastructure on the environmental sensitivities of the site including areas to be avoided, including buffers;	Appendix 1.
A description of any assumptions made and any uncertainties or gaps in knowledge;	Section 4.
A description of the findings and potential implications of such findings on the impact of the proposed activity, including identified alternatives, on the environment.	Sections 3.2 and 3.3
Any mitigation measures for inclusion in the EMPr	Section 3.8
Any conditions for inclusion in the environmental authorisation.	Section 8
Any monitoring requirements for inclusion in the EMPr or environmental authorisation.	Section 3.6
A reasoned opinion as to whether the proposed activity or portions thereof should be authorised and	Section 8
If the opinion is that the proposed activity or portions thereof should be authorised, any avoidance, management and mitigation measures that should be included in the EMPr, and where applicable, the closure plan.	Section 8
A description of any consultation process that was undertaken during the course of carrying out the study.	SLR responsibility.
A summary and copies if any comments that were received during any consultation process.	SLR responsibility.
Any other information requested by the competent authority.	Section 5.

6. Consultation with interested and affected parties (IAPs).
No specific consultation was undertaken or deemed necessary as part of this study.

7. Recommendations.
Given the distances from the open pits to the planned cemetery it is highly unlikely that blast related disturbance levels will cause damage to infrastructure.

The operating mines are located at considerable distances from the proposed new cemetery site. The influence of the ongoing mining on the cemetery location will be negligible. Ground vibration, airblast, flyrock, fumes and dust will have an insignificant impact at the proposed new cemetery location.

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There is no reason why the cemetery should not be located at the proposed location.

If you have any queries regarding the above, please contact me at 083 488 1392.

Yours sincerely

Erik Kohler.

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<u>Appendix 1</u>. Google Earth view of the existing open pits and the proposed new cemetery site.

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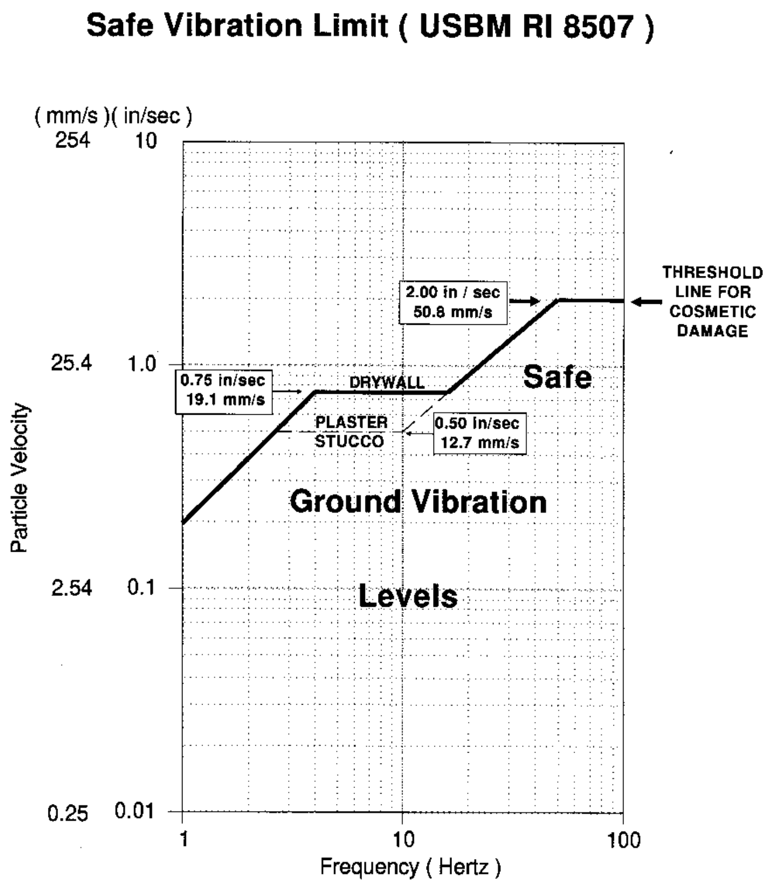
Vibration and Air Blast Limits

Ground Vibration - Building response to ground vibration
Although there are no legislated limits to vibration, the US Bureau of Mines limits are commonly applied in South Africa. The limiting curve is shown in Graph 1 and has been developed from empirical studies (Siskind *et.al.* 1980).



Graph 1. USBM curve that is generally used in South Africa. (After Chiappetta, March 2000)

The limiting curve in Graph 1 represents the limit for cosmetic damage to a house. The maximum ground vibration amplitudes are frequency dependent with higher frequencies allowing higher peak amplitudes. Most modern blasting seismographs will display the vibration data in terms of the USBM limiting criterion. In general, at lower frequencies, the ground vibration should not exceed 12.7 mm/s, but at higher frequencies, the limit can increase to 50 mm/s.

Appendix 2: Vibration and Airblast Limits.

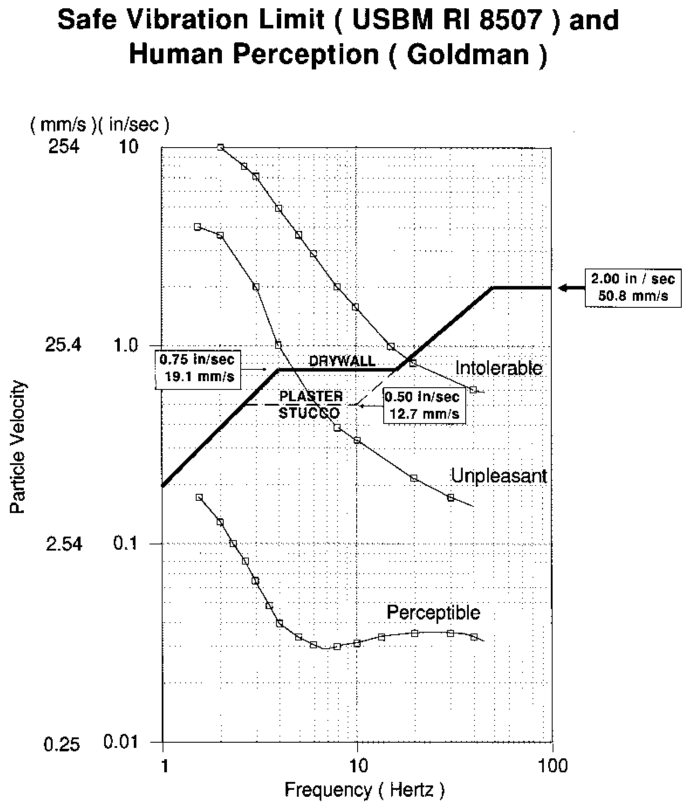
<u>Human response to ground vibration</u>

Although buildings can withstand ground vibration amplitudes of 12.7 mm/s or more, depending on the frequency, human beings are easily disturbed at lower levels. The typical human response to ground vibration is illustrated in the table below.

Effects on Humans	Ground Vibration Level mm/s
Imperceptible	0.025 – 0.076
Barely perceptible	0.076 – 0.254
Distinctly perceptible	0.254 – 0.762
Strongly perceptible	0.762 – 2.540
Disturbing	2.540 – 7.620
Very disturbing	7.620 – 25.400

Human response to vibration (Chiappetta, 2000)

Ground vibration levels of 0.76 to 2.54 mm/s received at a structure are quite perceptible, but the probability of damage is almost non-existent. Levels in the 2.54 to 7.6 mm/s can be disturbing and levels above 7.6 mm/s can be very unpleasant, although permanent damage is unlikely.



Graph 2. Human response curves compared with potential damaging limits. (After Chiappetta, 2000).

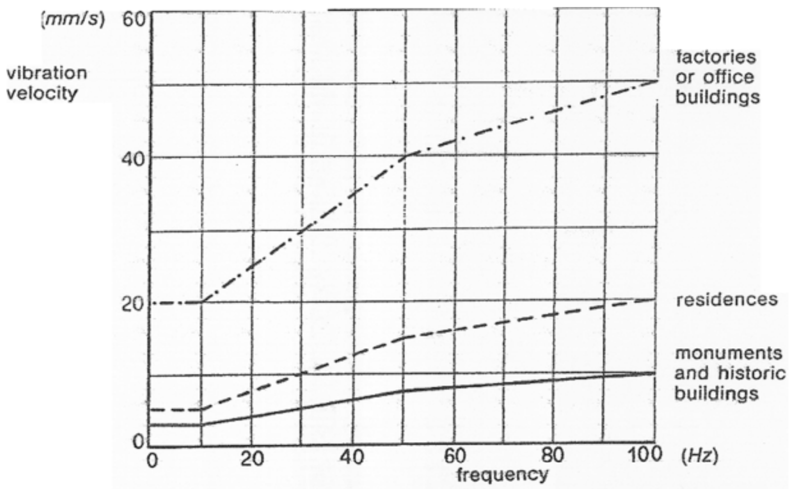
<u>Appendix 2 (cont)</u>: Vibration and Airblast Limits.

Human perception is also affected by frequency. The approximate human response curves are combined with the USBM limiting curve for damage in Graph 2. These curves slope in the opposite direction. In other words, humans are more tolerant to low frequency vibrations.

To avoid damaging buildings, the USBM limiting curve should be applied. However, to avoid constant complaints from neighbours, the vibration should preferably be kept beneath the *unpleasant* curve and definitely be kept beneath the *intolerable* curve.

<u>DIN STANDARD 4150 (Western Germany, 1983)</u>. Limit values of vibration expressed in mm/sec.

Recording spots / Type of structure	Foundations			Floor of the highest storey of the building
	< 10 *Hz*	10 − 50 *Hz*	50 − 100 *Hz*	Any frequency
1. Office or factory building	20	20 − 40	40 − 50	40
2. Residential building with plastered walls	5	5 − 15	15 − 20	15
3. Historic and other buildings to be treated with care	3	3 − 8	8 − 10	8
With frequencies > 100 Hz higher levels may be accepted				



Vibration velocity threshold for different types of constructions as a function of frequency, as defined by DIN STANDARD 4150 (West Germany)

It may be prudent to apply the DIN standard where 3rd world housing is encountered, as these buildings are often poorly constructed.

<u>Appendix 2 (cont)</u>: Vibration and Airblast Limits.

Air Blast Limits

As with ground vibration, there are no legislated limits to air blast amplitudes from blasting activity.

Siskind *et.al.* (1980), indicate that monitored air blast amplitudes up to 135 dB are safe for structures, provided the monitoring instrument is sensitive to low frequencies (down to 1 Hz). Persson *et.al.* (1994) have published the following estimates of damage thresholds based on empirical data.

120 dB	Threshold of pain for continuous sound
>130 dB	Resonant response of large surfaces (roofs, ceilings). Complaints start.
150 dB	Some windows break
170 dB	Most windows break
180 dB	Structural Damage

Damage thresholds for air blast.

References

Siskind, D.E., Stagg, M.S., Kopp, J.W. & Dowding, C.H., 1980. *Structure Response and Damage Produced by Ground Vibration from Surface Mine Blasting,* U.S. Bureau of Mines RI 8507.

Chiappetta, R.F., 2000, *Vibration/airblast controls, Damage criteria, record keeping and dealing with complaints*. The Institute of Quarrying, Southern Africa, Symposium, Durban

Persson, P-A, Holmberg, R and Lee, J, 1994, *Rock Blasting and Explosives Engineering*. CRC Press, USA.

Siskind, D.E., Stachura, V.J., Stagg, M.S. & Kopp, J.W., 1980. *Structure Response and Damage Produced by Airblast from Surface Mining,* U.S. Bureau of Mines RI 8485

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