

Cambrian CC

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25th November 2016

Dear Tim,

I have reviewed the information emailed to me and checked out the three proposed mining areas and their surroundings using Google earth. The proposed mining areas are remote. They are sparsely populated and developed. Infrastructure in the areas appears to be limited to farmhouses and other farm buildings.

Background.

You provided data tables showing the distances from the three proposed project areas to various sensitive receptors. The distances from each of the three blocks to the receptors ranged as follows:

Block	Closest property	Furthest property
Eastern Block	1.73km	11.4km
Quaggasfontein Block	4.60km	6.05km
Kareepoort Block	6.84km	9.14km

When we met we discussed the possible impact that blasting could have on the various properties. This is reviewed below.

Possible impact of blasting.

No information was provided relating to the proposed drill and blast procedures. However, irrespective of the size of a blast, the following blast related impacts may be experienced in the surrounding areas:

- Ground vibration is one of the major concerns.
- Airblast is a major concern and usually attracts the most attention.
- Unwanted side effects such as fly rock, after blast fumes and dust.

The nature and extent of the impacts are related to the size of the blast, distance from the blast and the prevailing weather conditions at the time of the blast.

Blast Design.

Prior to the start of blasting a proposed blast design should be modelled to determine the firing sequence, number of holes firing together and the combined charge mass per delay. Based on these figures the peak particle velocities can be calculated at the points of concern. These predictions should be compared to recognised standards - such as the United States Bureau of Mines Standard

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(USBM RI 8507) or the DIN standard - to ensure compliance. See Appendix 1 for a summary of these standards.

When acceptable results are obtained, the design should be fixed for use in the field.

Ground Vibration.

Ground vibration and air blast generally excite the greatest comment from people living in the neighbourhood. Ground vibration disturbances will need to be quantified to ensure compliance with recognised and accepted industry standards such as USBM RI 8507 or the DIN standard.

Factors Affecting Ground Vibration and Prediction of Ground Vibration Levels.

Ground vibrations are an undesirable 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 impact.

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 should initially be used as 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 1). In general, at lower frequencies, the ground vibration should not exceed 12.7

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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.

Nature of structure	PPV in mm/sec
Heavily reinforced concrete structures.	120
Property owned by concern performing blasting (minor plaster cracks acceptable)	84
Private property in reasonable repair, where public opinion is not an important consideration.	50
Private property where maximum level of public concern is taken into account.	12
National roads / Tar roads	150
Steel pipelines	50
Green Concrete i.e. aged for less than 3 days	5
Concrete > 10 days	20

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 nonexistent. Levels between 2.54 and 7.62 are disturbing and levels above 7.62 can be very unpleasant.

Human perception is also affected by frequency. The approximate human response curves are combined with the USBM limiting curve for damage (Graph 2, Appendix 1). 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.

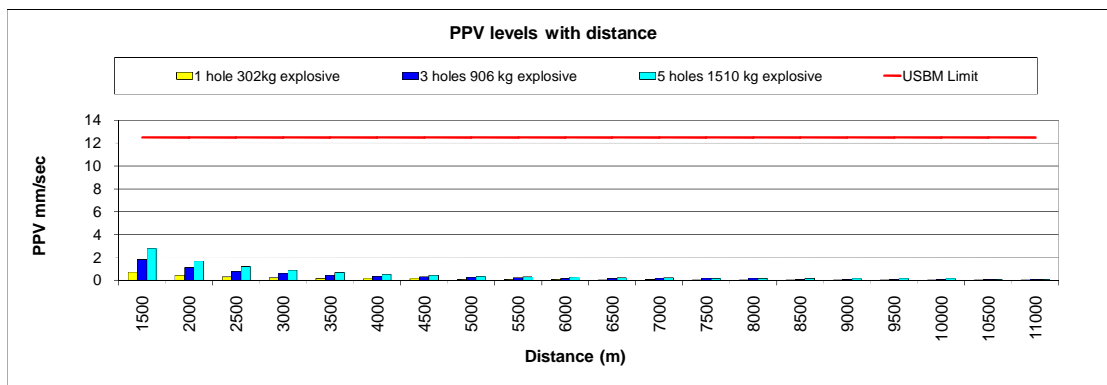
The drill and blast parameters for the mine have not been finalised as yet. However, based on my experience at a number of other operations, I modelled a blast layout using 168mm diameter holes and 15m bench heights to predict the ground vibration levels that could be experienced at various distances from the blasts. The burden and spacing dimensions used were 4.5m by 5.1m. This resulted in a powder factor of 0.88 kgs/cubic meter.

The number of holes firing together (and hence the charge mass) was progressively increased from 1 to 5 holes to determine the effect on the PPV levels at various distances. A bulk explosive with an average in hole density of 1.15 was used in the calculation.

In the data table below the potential impact to structures located at various distances around the proposed mining operations are shown. The explosive charge mass was progressively increased from 302kgs per delay (1 hole) to 1,510kgs per delay (5 holes).

VIBRATION	B West	B West	B West	B West	B West
Holes Detonated Per Delay	1	2	3	4	5
Combined charge mass firing	302	604	906	1208	1510
Distance increment in metres					
500	Production	Production	Production	Production	Production
Distance (m)	PPV (mm/s)	PPV (mm/s)	PPV (mm/s)	PPV (mm/s)	PPV (mm/s)
1500	0.73	1.29	1.81	2.29	2.76
2000	0.45	0.80	1.12	1.43	1.71
2500	0.31	0.56	0.78	0.99	1.19
3000	0.23	0.41	0.58	0.73	0.88
3500	0.18	0.32	0.45	0.57	0.68
4000	0.14	0.26	0.36	0.45	0.55
4500	0.12	0.21	0.30	0.37	0.45
5000	0.10	0.18	0.25	0.31	0.38
5500	0.09	0.15	0.21	0.27	0.32
6000	0.07	0.13	0.18	0.23	0.28
6500	0.06	0.12	0.16	0.20	0.25
7000	0.06	0.10	0.14	0.18	0.22
7500	0.05	0.09	0.13	0.16	0.19
8000	0.05	0.08	0.11	0.14	0.17
8500	0.04	0.07	0.10	0.13	0.16
9000	0.04	0.07	0.09	0.12	0.14
9500	0.03	0.06	0.09	0.11	0.13
10000	0.03	0.06	0.08	0.10	0.12
10500	0.03	0.05	0.07	0.09	0.11
11000	0.03	0.05	0.07	0.09	0.10

The data tabulated above also shows that the predicted ground vibration levels are far too low to cause damage to structures. It 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.



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 surrounding the mine will control the attenuation of the shock waves. The geological controls are not easily observed but can be determined using the IsoSeismic analysis technique, which allows an IsoSeismic contour map to be constructed around the mine. The data obtained can be used to determine site specific constants for use in the prediction of ground vibration in the area.

Airblast.

Airblast is usually 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).

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 but it is recommended that the airblast be kept below the 130dB level. (Overcharged holes can generate amplitudes that exceed 142dB). Suggested threshold limits for air blast (below) have been proposed by Personn et.al. 1994.

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 and this should be the focus.

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.

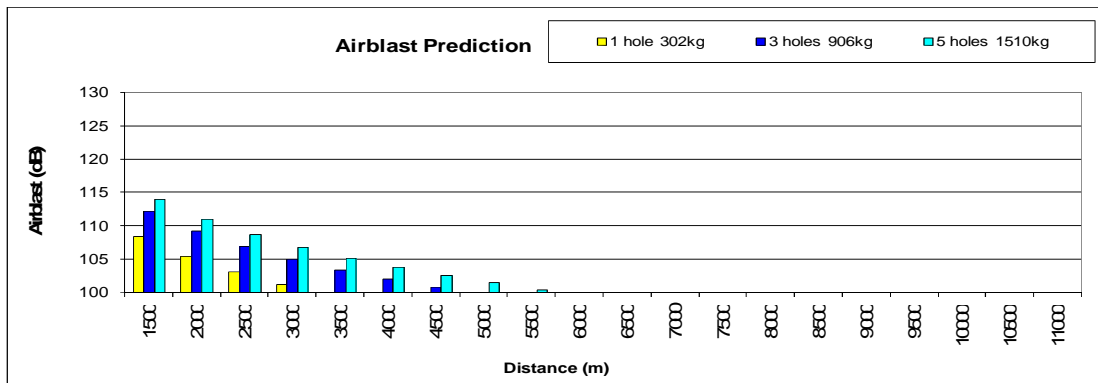
L = Airblast level (dB)

D = Distance from source (m)

W = Charge mass per delay (kg)

I have calculated the air blast levels using the same charge masses as were used for the prediction of ground vibrations. The airblast levels relating to the surface infrastructure are given in the table below. The data is then graphed.

AIRBLAST	B West	B West	B West	B West	B West
Holes Detonated Per Delay	1	2	3	4	5
Combined charge mass firing	302	604	906	1208	1510
Distance increment in metres					
500	Production	Production	Production	Production	Production
Distance (m)	dB	dB	dB	dB	dB
1500	108	111	112	113	114
2000	105	108	109	110	111
2500	103	105	107	108	109
3000	101	104	105	106	107
3500	100	102	103	104	105
4000	98	101	102	103	104
4500	97	99	101	102	103
5000	96	98	100	101	101
5500	95	97	99	100	100
6000	94	96	98	99	100
6500	93	96	97	98	99
7000	92	95	96	97	98
7500	92	94	95	96	97
8000	91	93	95	96	97
8500	90	93	94	95	96
9000	90	92	94	95	95
9500	89	92	93	94	95
10000	89	91	92	93	94
10500	88	91	92	93	94
11000	88	90	91	92	93



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

Unwanted Side Effects - Fly Rock.

Side effects such as fly rock or excessive post blast fumes are undesirable and usually occur unexpectedly, sometimes for unknown reasons. This makes proactive preventative management difficult. If any incidents occur they should immediately be investigated to determine the likely cause to allow corrective action to be taken.

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.

The only solution to the above is to plan and design the blast correctly. This must be followed by care and good control during the charging up of the blast. Holes must receive the correct quantity of explosive. Correct stemming lengths must be used. As a safety measure a minimum safe distance (normally 500m) from the

blast area must be cleared of people and animals. The drill and blast company must define the procedures and method.

Unwanted Side Effects - 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:

- Poor quality control and incorrect formulation;
- Excessively long sleep times;
- Damage to the explosive;
- Inadequate water resistance;
- Poor ground conditions;
- Premature loss of confinement;
- Inadequate priming; and
- Insufficient charge diameter.

If fumes occur after a blast then the immediate vicinity of the blast area must be kept clear until these have dissipated. The wind direction and conditions must also be kept in mind to ensure that the fumes do not impact further afield.

It is difficult to ensure that post blast fumes never occur because some of the factors above are outside the blasters control. The best tools here are to ensure that strict quality control standards are in place and to exercise ongoing care and control during all stages of the charging up side of the operation. This is easily controlled if packaged explosive is used, as this is factory manufactured. If Anfo or bulk explosive is used, then the on-site QC controls are critical as the products are blended and placed directly into the blasthole. Problems such as running out of diesel (Anfo) or gassing solution (bulk) are not uncommon.

Damage Survey.

The damage survey involves inspecting buildings externally and internally. Any damage noted is photographed for future reference. The photo data base can then be included as a baseline study. Although every effort is made to photograph all damage this cannot be guaranteed. Practical problems such as no access to properties, locked rooms, rooms too dark to allow photographs, walls obscured by furniture, etc. can result in damage not being recorded.

A desk top study will provide a guideline on the disturbance levels that can be expected at various distances from the proposed mines and this information together with a physical inspection of the area around the proposed mines will help determine the nature and extent of any inspection.

An initial appraisal of the distances to various structures as well as viewing the proposed mining areas using Google earth suggests that the above study will probably not be required. This should be confirmed by mine management prior to the start of blasting.

In South Africa a blast safety radius of 500m is applied for safety reasons. This may be insufficient and I recommend that an inspection radius of at least 1,000m be used. In addition to the above, I suggest that sensitive buildings (e.g. schools, hospitals, churches) outside of this radius be identified and included in the inspection.

Initial and ongoing monitoring work.

The initial blasts should be monitored using industry approved seismographs. These seismographs record the ground vibration levels as well as the airblast levels simultaneously. The seismographs should be positioned at specific locations around the mine operations. The seismograph records should be saved along with the blast schedule for every blast.

Conclusions.

The predicted ground vibration levels are far too low to cause damage to structures.

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

The unwanted side effects, under normal circumstances, should have no impact on the properties as they are located too far away from the mining operations. The impact to some degree can be influenced by the prevailing weather conditions. Low cloud, temperature inversions and strong winds can increase the size of the impact footprint.

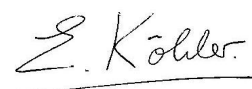
Permanent seismograph stations will be expensive to install and will serve very little purpose as the properties are all very far from the proposed mining operations. The disturbance levels experienced (if any) will be too low to cause damage to structures. However, I recommend as a precaution that the initial blasts be monitored to ensure that no unexpected disturbances are being experienced and that the disturbance levels are acceptable. Once this is known then random ad hoc monitoring can be carried out as per the requirements of mine management.

I can supply portable hand held seismographs that can be hand placed for each blast. This will require trained people on site that can carry out this work.

In addition to the above remote monitoring of noise, dust levels, weather and other parameters can be carried out. Please see Appendix 2 for information on some of these systems.

Please contact me by e-mail or at 083 488 1392 if you require any additional information.

Yours sincerely



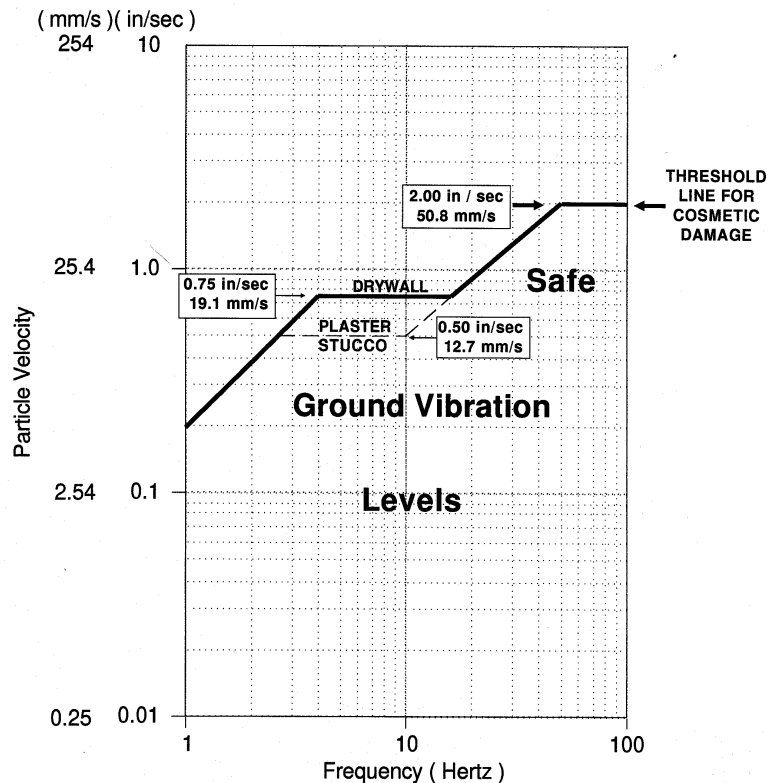
Erik Kohler.

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).

Safe Vibration Limit (USBM RI 8507)



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 1: Vibration and Airblast Limits.

Human response to ground vibration

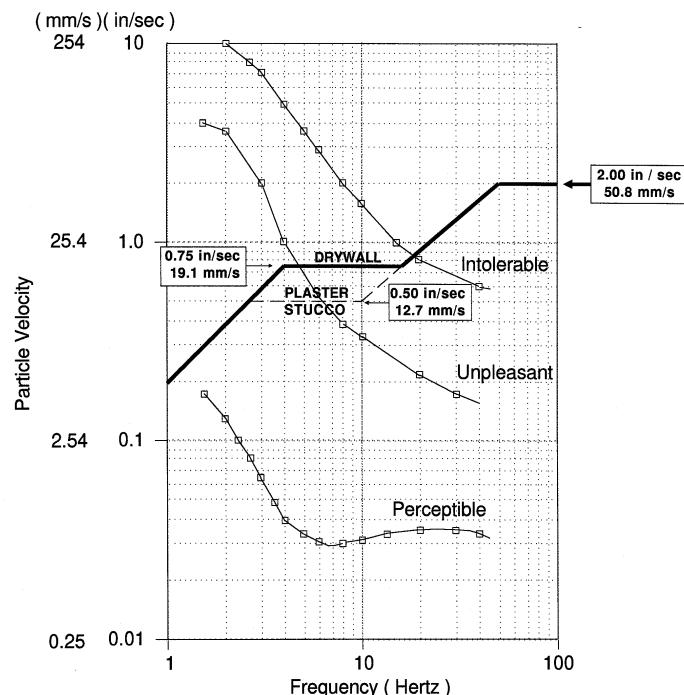
Although buildings can withstand ground vibration amplitudes of 12.7 mm/s or more, depending on the frequency, human beings are easily disturbed at lower levels. The typical human response to ground vibration is illustrated in the table below.

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 nonexistent. 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.

Safe Vibration Limit (USBM RI 8507) and Human Perception (Goldman)



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

Appendix 1 (cont): Vibration and Airblast Limits.

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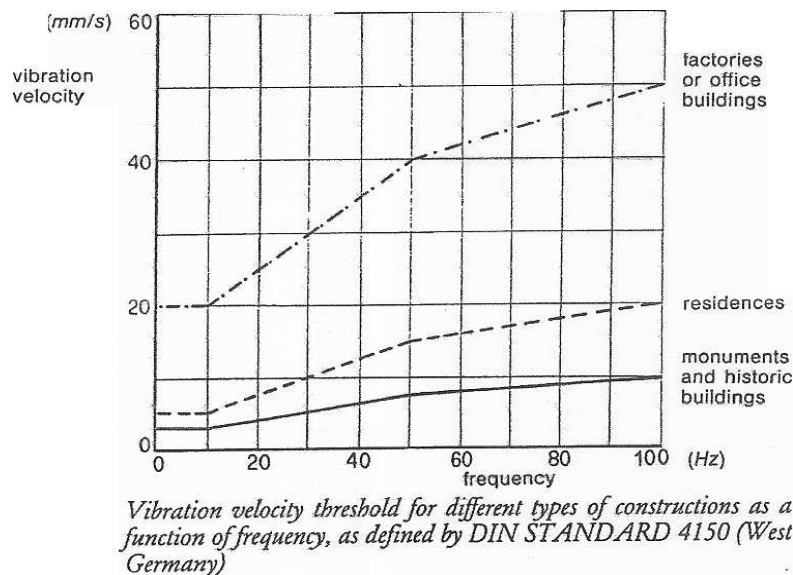
Human perception is also affected by frequency. The approximate human response curves are combined with the USBM limiting curve for damage in Graph 2. These curves slope in the opposite direction. In other words, humans are more tolerant to low frequency vibrations.

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.

DIN STANDARD 4150 (Western Germany, 1983). 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



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

Appendix 1 (cont): Vibration and Airblast Limits.

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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

Appendix 1: Vibration and Airblast Limits.

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Various types of remote monitoring instrumentation.

In addition to blast monitoring, Cambrian in cooperation with Vibra-Tech (VT) or White Seismology (WS) can provide the following services.

- Remote vibration monitoring of ground vibration and airblast using either Vibra-Tech or White Seismology equipment.
- Remote noise monitoring (VT).
- Remote weather monitoring (VT).
- Remote dust level monitoring (VT).
- Website development for hosting of all remote data (VT).

Remote Monitoring.

I can offer continuous remote monitoring services that provide hands-off monitoring, analysis, and reporting of ground vibration, sound, dust, and environmental data. This service provides efficient, cost-effective data collection while placing the responsibility of gathering quality data in the hands of third-party experts.

The development of solar powered, remote-accessible monitoring stations allows for permanent placement of a reliable, consistent setup. Through the use of wireless technology, data can be uploaded to a customized website in a timely manner. Alarm systems can also be implemented for individual sensors to inform key personnel via email or text message if predetermined warning levels are exceeded. All remote monitoring stations are stand-alone units that are powered by a 12 volt deep-cycle batteries and solar chargers. Customized security enclosures have been designed and fabricated for added security.

Remote monitoring is only possible if good communication links are available.

Vibration Monitoring.

Remote vibration monitoring will be conducted using a GeoSonics 3000SR seismograph system or a White Seismology Mini Seis seismograph to measure ground vibration and air overpressure. After a blast we will download, review vibration and air overpressure results, and upload the event files to the customized website in a timely manner (Vibra-Tech). The data will be compared to the applicable criteria for ground vibration and air overpressure, and trend analyses of the seismic and air overpressure data will be available for assistance with future blast planning. In addition, we can review the results in order to discuss the results with key project personnel if necessary.

The various options available need to be discussed to determine what the requirements are. I detailed costing can then be prepared based on specifications and available budget.

Noise Monitoring.

Remote noise monitoring will be conducted using a Larson Davis System 820 Type 1 sound level meter to measure noise in dBA. Noise levels will be uploaded to the website. The noise levels will be displayed graphically and compared to any applicable threshold levels and/or noise criteria.

Weather Monitoring.

Remote weather monitoring will be conducted using an electronic rain gauge, anemometer and wind vane, barometer, and a temperature and humidity sensor. Weather data will be uploaded to the website and archived and displayed graphically. Additional sensors, such as a water level meter, can be added to this system if required.

Dust Monitoring.

Remote dust monitoring will be conducted using a Thermo Environmental Real Time Ambient Dust Monitor. These systems are commonly used for construction and fence line dust monitoring of either PM10 or Total Suspended Particles (TSP). The dust data, including wind speed and direction, will be uploaded to the website and archived and displayed graphically.

Customized Website Development.

Vibra-Tech will develop a customized website that will include all remote monitoring data. All pertinent data will be archived on the website in organized, sortable tables. The data will also be displayed graphically, related to established criteria, and added to different trend analyses. The location of blasting activity and the location of the remote monitors will be displayed on an aerial map. Necessary project personnel will be assigned login credentials and be trained on the use of the website.

This website option is currently not available for use with the White Seismology equipment.

General.

The monitoring stations should ideally be established in a secure area e.g. mine property or private property where there is good security. Although the instrumentation is housed in a solid locked steel box there is no guarantee that it will not be tampered with or possibly stolen. In the event that the equipment is damaged or stolen then the mine is responsible for the repair or replacement of the equipment at their cost.

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Appendix 2: Various remote monitoring instrumentation available.

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