Cambrian CC

Reg. No. 2001/031939/23

P O Box 977
Irene
0062
South Africa

Ms. Marline Medallie
SLR Consulting (South Africa) (Pty) Ltd
P O Box 1596
Cramerview
2060

11th May 2019

Dear Marline,

BLAST EVALUATION OF THE UNDERGROUND DRILL AND BLAST OPERATION FOR THE PROPOSED WEST WITS PROJECT.

1. Background.

Blasting in the normal course of mining takes place during open pit and underground mining. For the proposed West Wits Mining project no blasting will take place for the open pits. Blasting at the proposed West Wits operation will only take place underground at depths ranging from 50 metres (m) up to 3 000 m.

To help manage the situation a systematic approach to the drill and blast operation needs to be adopted. This approach should initially assess the potential impact of the drill and blast operation and then control and manage the day-to-day operations to ensure that the impacts are managed such that the disturbance levels fall within accepted industry norms. The aim of this report is to assess the possible impact of the underground drill and blast operation and to provide guidelines to help ensure that the blasting process is correctly implemented.

2. Mine Site.

The area of the mining operation is located in an area south of Roodepoort and to the north of Soweto in the City of Johannesburg Metropolitan Municipality, Gauteng (Appendix 1).

The proposed project would make use of open pit mining methods as well as underground mining methods. No drilling and blasting will be required in the open pits as these will be mined by making use of Xcentric rippers. The ground vibration and noise disturbance levels associated with the use of the rippers were measured in May 2018. Seismographs were set up at distances ranging from 15 m up to 45 m from the rippers. The measurements showed that the disturbance levels were highest close to the Xcentric ripper's area of operation and that these levels attenuated (decreased) rapidly with increase in distance. At distances greater than 100 m the disturbance levels will be insignificant and of no consequence.

The underground mining method would make use of conventional drill and blast breast mining methods. Small diameter holes and light charge masses will be used for the blasting operations. The ground vibration levels caused by the blasting will be low. If any vibrations are felt on surface, the levels will be far too low to cause damage to structures. Airblast will have no effect on surface as it will be confined to the underground workings.

3. Objective.

This report considers the possible impact of the underground blasting operations on the surrounding areas. It provides an assessment of the possible disturbance levels that may be experienced at various distances from the underground workings. It considers the preliminary work that should be carried out prior to the start of blasting and then the ongoing monitoring work that is required when blasting is underway.

The following aspects of the blasting operation were assessed:

3.1 Blast design and general safe blasting practice.
3.2 Ground vibration levels.
3.3 Airblast levels. This is an underground mining operation so airblast will not impact on third parties on surface.
3.4 Side effects such as fly rock, after blast fumes and dust. These will be confined to the underground workings and will not impact on third parties on surface.
3.5 Disturbance monitoring. This may be an aspect to consider at the start of the drill and blast operations as a precautionary measure. The equipment required, placing of equipment and the standards against which disturbance levels are measured and assessed for compliance are reviewed.
3.6 Mitigation measures. A number of suggestions are made. These generally affect all aspects of the operation so the points have been grouped together.

3.1 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 (USBM RI 8507) and / or the Deutsches Institut für Normung (DIN standard) - to ensure compliance. See Appendix 2 for a summary of these standards. When acceptable results are obtained, the design should be fixed for use.

The final blast design should be marked and drilled off on the face. After the blast is drilled off and charging commences then the process should be audited to ensure that all stages of the operation are proceeding as per the design. The blast pattern, the hole depths and the accuracy of the drilling should be checked. The explosive charge mass per hole and the final stemming lengths must be verified. It is now a requirement that a third of the hole must be stemmed closed.

3.2 Ground Vibration.

Ground vibration may attract comment from people in the vicinity of a mine. Ground vibration disturbances will need to be quantified to ensure compliance with recognised and accepted industry standards such as the USBM RI 8507 or the DIN Standard (see Appendix 2 for a summary of these standards).

Factors Affecting Ground Vibration and Prediction of Ground Vibration Levels.

Ground vibrations are an inevitable 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 in millimetres per second (mm/sec).

D = Distance to property of concern in metres (m).

E = Mass of explosive per delay in kilograms (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 1.143 for “a” and a value of –1.6 for “n” can be used (Chiappetta, training course). 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 Table 3.2.1 below (This information is taken from a presentation given by F Chiappetta of Blasting Analysis International, an American based company).

Table 3.2.1: PPV damage thresholds for various infrastructure.

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 where maximum level of public concern is taken into account.	12
National roads / Tar roads	150

Members: Erik Kohler (managing)
Tel: ….. Fax to mail: +27 865501012 Cell: 083 488 1392
e-mail: ekohler@absamail.co.za

Nature of structure	**PPV in mm/sec**
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 likelihood that damage to property will occur is almost non-existent. Levels between 2.54 and 7.62 are considered to be 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 to property (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.
Some information relating to the blast parameters was provided by the applicant. Based on this the model was setup to assess blast layouts using 32 mm diameter holes drilled off to final depths of 1.2 m. The type of explosive planned for use was given as ‘cartridges.’ The study used the Explogel V8 cartridge in the modelling. This has a density of 1.25 gram per cubic centimetre (g/cc).

The number of holes firing together (and hence the charge mass) was progressively increased from 1 to 6 holes to determine the effect on the PPV levels at various distances. The shortest distances from the blasts will be to the adjoining underground workings. The distances to the surface could be as close as 50 meters but this distance will obviously increase as mining progresses. The distance was progressively increased from 50 m to 700 m to simulate this. The following PPV levels were predicted:

Members: Erik Kohler (managing)
Tel: ….. Fax to mail: +27 865501012 Cell: 083 488 1392
e-mail: ekohler@absamail.co.za

Table 3.2.2: Predicted PPV levels for increasing charge mass and distance.

VIBRATION	W Wits	W Wits	W Wits	W Wits	W Wits	W Wits
Holes Detonated Per Delay	1	2	3	4	5	6
Combined charge mass firing	0.73	1.45	2.18	2.90	3.63	4.35
Distance increment in metres						
50	Production	Production	Production	Production	Production	Production
Distance (m)	PPV	PPV	PPV	PPV	PPV	PPV
50	1.38	2.44	3.42	4.33	5.21	6.05
100	0.44	0.78	1.09	1.38	1.66	1.93
150	0.23	0.40	0.56	0.71	0.85	0.99
200	0.14	0.25	0.35	0.44	0.53	0.61
250	0.10	0.17	0.24	0.30	0.37	0.43
300	0.07	0.13	0.18	0.23	0.27	0.31
350	0.06	0.10	0.14	0.17	0.21	0.24
400	0.04	0.08	0.11	0.14	0.17	0.20
450	0.04	0.07	0.09	0.12	0.14	0.16
500	0.03	0.05	0.08	0.10	0.12	0.14
550	0.03	0.05	0.07	0.08	0.10	0.12
600	0.02	0.04	0.06	0.07	0.09	0.10
650	0.02	0.04	0.05	0.06	0.08	0.09
700	0.02	0.03	0.04	0.06	0.07	0.08

Analyses of the above data shows that the PPV levels for any number of holes firing together all decrease as the distance increases. By way of example, if the data for two holes firing together is reviewed it shows that at a distance of 50 m from the blast a PPV level of 2.44 mm/sec is predicted. In human response terms a PPV level of 2.44 mm/sec falls into the strongly perceptible category. As the distance increases the PPV levels reduce rapidly and at a distance of 200 m the level has reduced to 0.25 mm/sec. This falls into the barely perceptible human response category. At a distance of 700 m the level has reduced even further to 0.03 mm/sec which also falls into the barely perceptible human response category. Disturbances at these levels will be imperceptible. As the mining depth increase the impacts will reduce even further and will be of no significance.

The data tabulated above shows how the PPV levels for a given charge mass attenuate rapidly with increase in distance. This can be seen more clearly when the data is graphed (Figure 1 below). When the explosive detonates the shock wave travels in all directions throughout the rock mass. The distances indicated are therefore measured from the blast vertically to the ground surface, or from the blast horizontally to a receptor point, or from the blast on an incline distance to a receptor point.

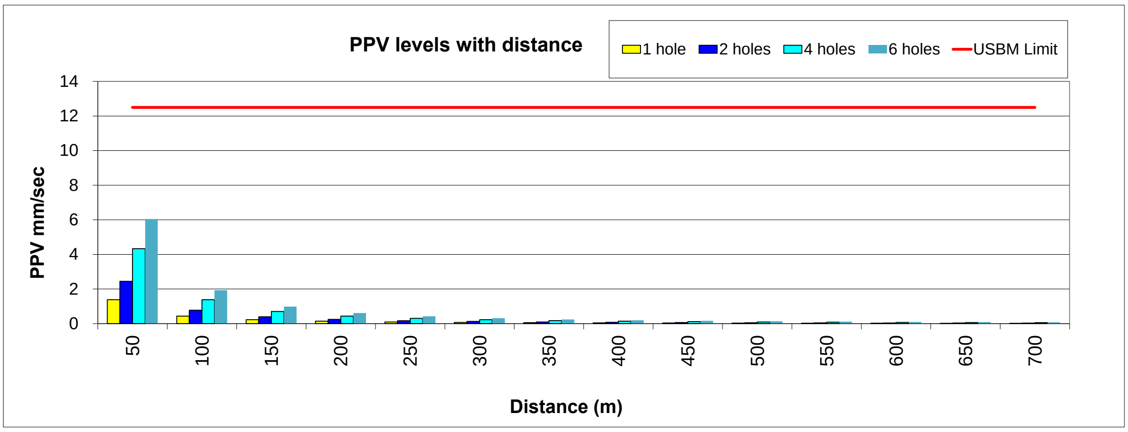


Figure 1: Predicted PPV levels plotted against distance.

As expected, the highest PPV levels occur at points closest to the blast. The disturbance levels attenuate rapidly with increase in distance and at distances in excess of 100 m the levels are well within the acceptable limits. Given the increasing depth of the mining activity and the small charge masses being fired at one time, it is highly unlikely that any disturbances will be felt on the surface of the ground. If any vibrations are felt on surface, the levels will be far too low to cause damage to structures.

Potential areas of concern are the production and magazine facilities of Maxam Dantex South Africa (MD). A section of the underground workings will pass underneath the above facilities. MD has indicated their concerns related to the possible structural integrity deterioration of surface infrastructure that is related to underground mining. Their biggest concern appears to be ground instability and sinkhole development. The direct impact of blasting on the MD infrastructure should be quantified through measurement when the underground operations are underway.

In the experience of the specialist 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.

3.3 Airblast

This section is included for the sake of completeness. Given that blasting will take place underground at increasing depths airblast will have no effect on surface infrastructure as the impact will be confined to the underground workings.

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 and Walter 1990).

Airblast Prediction.

Given the variables associated with airblast any attempt to predict air blast levels <u>can only be regarded as subjective</u>. In the opinion of the specialist 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:

$$L = 165 - 24 \text{ Log10 } (D/W^{0.33})$$

Where

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

The study has calculated the air blast levels using the same charge masses that were used for the prediction of ground vibrations. The predicted levels at increasing distances are given in Table 3.3.1 below. The data is graphed (Figure 2) against the Persson recommended limit (Persson *et.al.*(1994).

Table 3.3.1 Predicted airblast levels for increasing charge mass and distance.

AIRBLAST	W Wits	W Wits	W Wits	W Wits	W Wits	W Wits
Holes Detonated Per Delay	1	2	3	4	5	6
Combined charge mass firing	0.73	1.45	2.18	2.90	3.63	4.35
Distance increment in metres						
50	Production	Production	Production	Production	Production	Production
Distance (m)	**dB**	**dB**	**dB**	**dB**	**dB**	**dB**
50	123	126	127	128	129	129
100	116	118	120	121	121	122
150	112	114	115	116	117	118
200	109	111	112	113	114	115
250	106	109	110	111	112	113
300	104	107	108	109	110	111
350	103	105	107	108	108	109
400	101	104	105	106	107	108
450	100	103	104	105	106	106
500	99	102	103	104	105	105
550	98	101	102	103	104	104
600	97	100	101	102	103	103
650	96	99	100	101	102	103
700	96	98	99	100	101	102

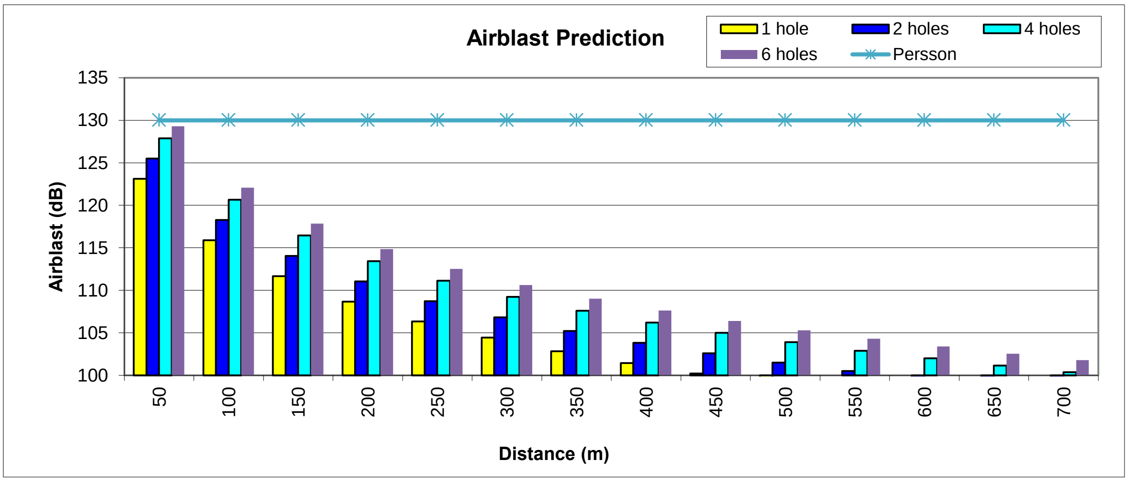


Figure 2: Predicted airblast levels plotted against distance.

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

This is an underground operation. As such, airblast will have no impact on surface and therefore poses no risk to third parties.

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 breaking face or the surface of the blast. The main causes are under-burdened holes, geological discontinuities, poor blast timing leading to over confinement of holes and overcharged blast holes that result in hole blow outs. Secondary blasting can also produce fly rock.

This is an underground operation. As such, flyrock will have no impact on surface. It therefore poses no risk to third parties.

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.

It is difficult to ensure that post blast fumes never occur because some of the factors mentioned 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 are used, as this is factory manufactured.

3.5 Disturbance Monitoring – Ground Vibration and Airblast.
It is recommended that a number of blasts are monitored at areas of concern in the vicinity of the underground workings. This may appear to be unnecessary but blasting at the shallow depths indicated will cause disturbances that are perceptible on surface. The intention is to record the ground vibration disturbance levels that are related to blasting. It is not necessary to monitor airblast. The measurements made can be used to demonstrate that the vibration amplitudes are low and that they comply with accepted industry norms. An independent third party should carry out the disturbance monitoring work.

Disturbance monitoring should be carried out using industry standard seismographs. The ground vibrations are measured in three directions. The three primary measurements can be plotted directly against an accepted standard, the two most common being the USBM and DIN standards. The USBM is most commonly used in South Africa. Attached are two printouts of measurements taken of a blast event (Appendix 3). The first shows the data measured at a specific monitoring station plotted against the USBM standard and the second shows the same data plotted against the frequency spectrum.

3.6 Mitigation Measures.
A number of measures are suggested to ensure that the drill and blast operation proceeds smoothly. Some of the measures (e.g. quality acceptance) apply to specific areas of the operation. Others apply to a number of aspects of the operation to varying degrees.

- Exercise ongoing care and control during all stages of the drilling and blasting operation. Check, check and check again.

- Prior to charging up the blast, the holes drilled should be inspected and all 'problem' holes identified for corrective action. Examples of 'problem' holes could include holes that are under-burdened, holes that are short drilled, holes surrounded by badly cracked ground and off pattern holes that could potentially lead to problems.
- Production quality control checks must be implemented as part of the Standard Operating Procedures. This is particularly important if re-pump explosives are being used. During charging up of the holes the re-pump explosive product should be sampled on an ongoing basis to ensure acceptable quality.
- After charging up is complete and prior to stemming the holes closed, they should be taped to determine the explosive column rise to ensure that the required stemming length is obtained. Any errors must be corrected before the hole is stemmed closed.
- The tie up should be carried out according to the blast plan to ensure that the timing and sequencing of the blast proceeds as planned.
- If fumes occur after a blast then the area must be kept clear until these have dissipated. The stipulated re-entry times must be enforced.

Keep accurate and comprehensive blast records. All of the blast parameters as well as the timing and sequencing used to delay the blast should be recorded, as the individual seismograph measurements made need to be linked to the blasts. The blast information can be referenced and used to assist with future blast designs. To facilitate this, the drill and blast contractor should keep accurate records of the following,:
- Blast type (e.g. Reef, stope, development etc.);
- Hole diameter drilled;
- Final drilled hole depths;
- Blast pattern dimensions, number of rows and holes per row;
- Total number of holes per blast – design and actual;
- Position of any additional or relieving holes;
- Any irregularities in the blast such as under-burdened or overburdened holes;
- Explosive type used to charge the blast;
- Explosive charge mass per hole and the total amount of explosive used per blast;
- The explosive column rise and the final stemming length achieved;
- Details of the final blast tie up with a schematic showing the position and value of the time delays used as well as the number of holes per delay;
- The date and time of firing the blast.

4. Knowledge Gaps.

The prediction of the possible disturbance levels at various distances 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. However, prior to the start of the drill and blast operation these figures must be reviewed to correct for any variances between 'actual' versus 'modeled'.

5. General Information and National Environmental Management Act, Regs 2014 (NEMA).

The scope of this report was to assess the potential impact of blasting activities on areas surrounding the proposed underground development and focused on:
- Prediction of ground vibration for increasing charge mass at various distances;

- Prediction of air blast as above; and
- Assessment of unwanted side effects such as fly rock, post blast fumes and dust.

The report was compiled to provide input to assist with information required to assess proposed management measures as well as possible alternatives. It addresses routine ongoing drill and blast applications.

The specialist's (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, 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.

The following is provided in accordance with NEMA Appendix 6.

NEMA Regs (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 duration, 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 inclusive of equipment and modelling used.	Section 4.
Details of an assessment of the specific identified sensitivities of the site related to the proposed activity or activities and its associated structures and infrastructure, inclusive of a site plan identifying site alternatives.	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 or activities.	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, activities or portions thereof should be authorised	Section 8

If the opinion is that the proposed activity, activities 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	See Note 1 below.
A summary and copies if any comments that were received during any consultation process	See Note 1 below.
Any other information requested by the competent authority.	Section 5.

Note 1: No specific consultation was undertaken or deemed necessary as part of this study. Comments received from the public by SLR South Africa as part of the Environmental Impact Assessment process for an application for a Mining Right for the proposed West Wits Project were considered in the undertaking of this study.

6. Suggestions.
It is suggested that the initial blasts be audited and monitored. The purpose of the exercise is to spot potential problems to allow these to be corrected before a blast is set off. The audit helps ensure compliance with design and addresses "finger problems" such as overcharged holes, under-burdened holes etc. These oversights need to be managed accordingly as any errors at this stage can have knock on effects that can increase disturbance levels significantly.

7. Consultation with interested and affected parties (IAPs).
See Note 1, NEMA table, section 5.

8. Recommendations.
The modelling results indicate that the disturbance levels that could be experienced at various distances from the planned underground operation should not cause damage to surface infrastructure.

If the drill and blast procedures for the proposed West Wits Project are well controlled and executed then there is no reason why this activity should not be authorised and carried out. It follows that the mitigation measures/recommendations and monitoring requirements as outlined in this report should form part of the conditions of the environmental authorisation.

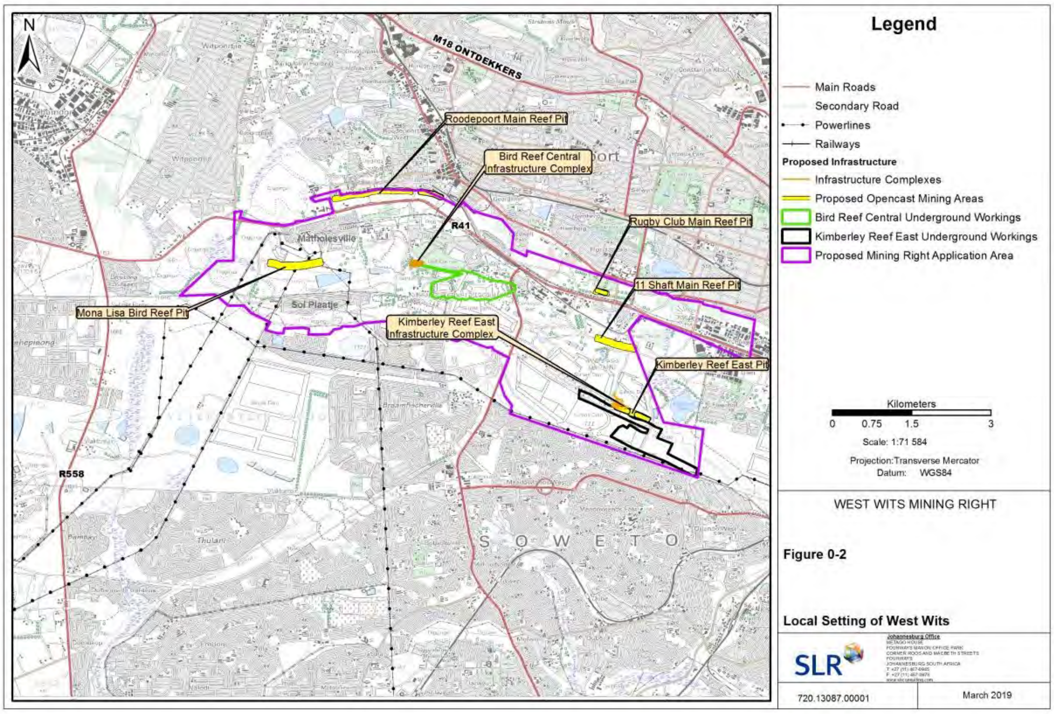
If you have any queries regarding the above, please contact me at 083 488 1392.

Yours sincerely

E. Kohler

Erik Kohler.

Members: Erik Kohler (managing)
Tel: ….. Fax to mail: +27 865501012 Cell: 083 488 1392
e-mail: ekohler@absamail.co.za

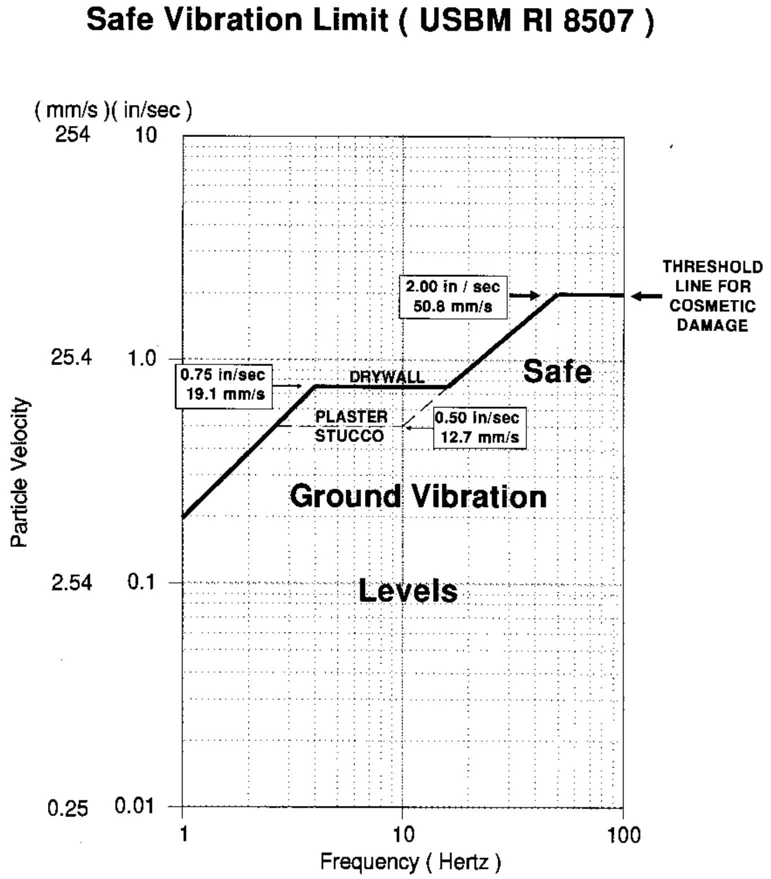


<u>Appendix 1</u>. Locality map of the proposed West Wits Mining Project

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.

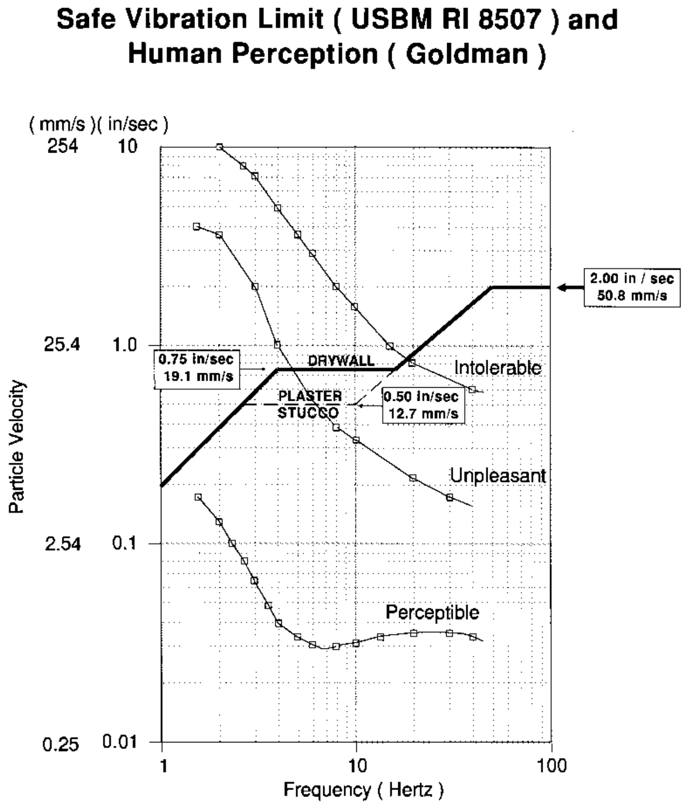
<u>Human response to ground vibration</u>

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.

<u>Table 1: Human response to vibration (Chiappetta, 2000)</u>

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

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.



<u>Graph 2</u>: Human response curves compared with potential damaging limits (After Chiappetta, 2000).

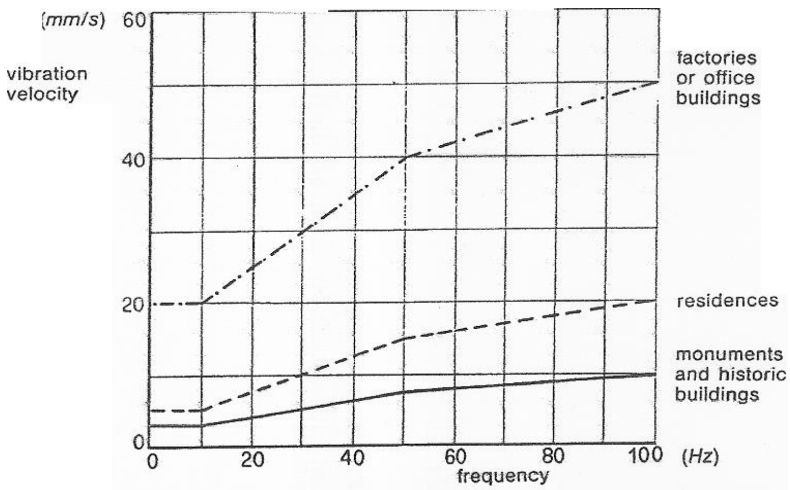
<u>Appendix 2 (cont)</u>: Vibration and Airblast Limits.

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)

<u>Graph 3:</u> DIN standard.

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

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

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.

Table 2: Damage thresholds for air blast.

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

References

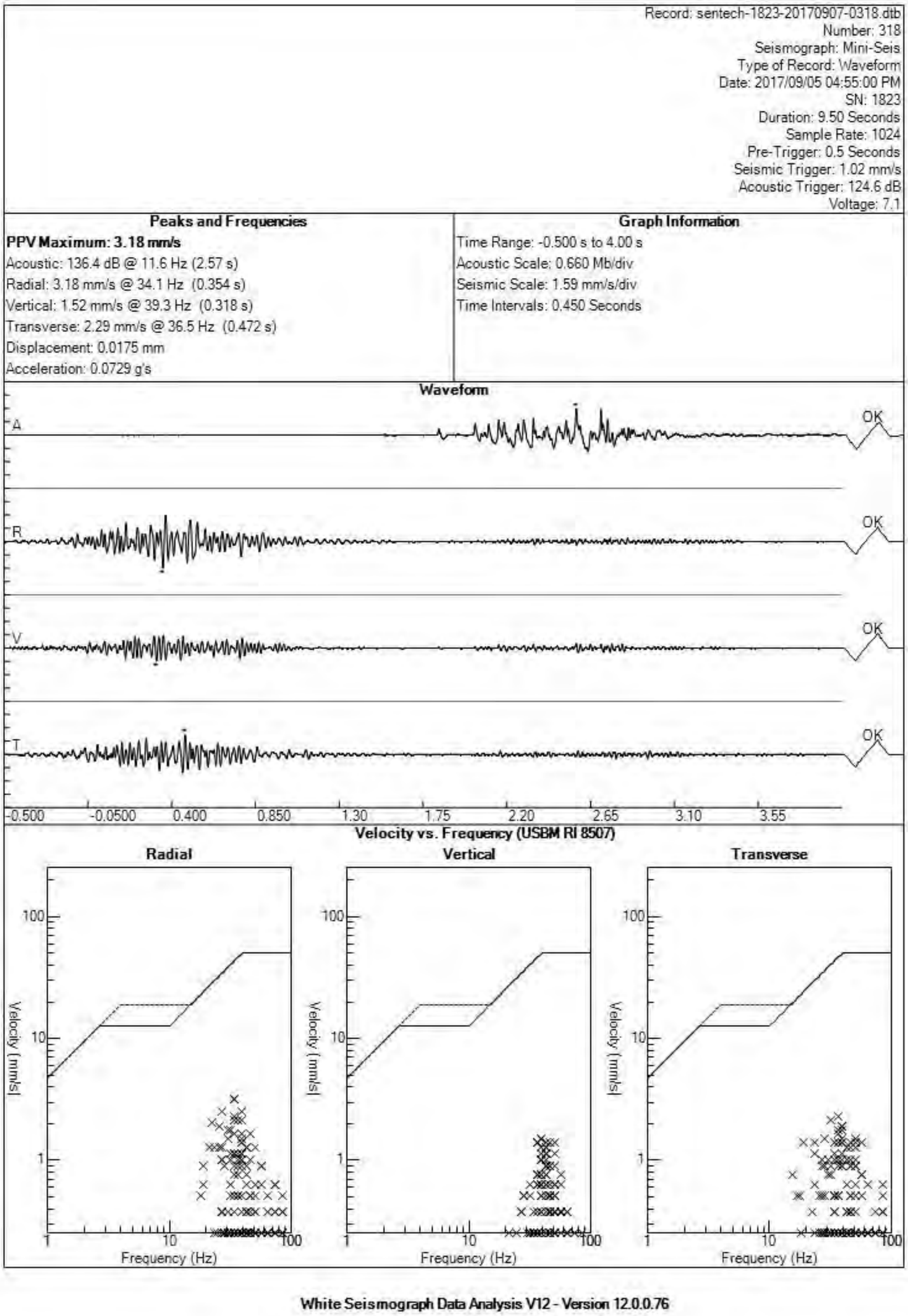
Siskind, D.E., Stagg, M.S., Kopp, J.W. & Dowding, C.H., 1980. *Structure Response and Damage Produced by Ground Vibration from Surface Mine Blasting,* U.S. Bureau of Mines RI 8507.

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

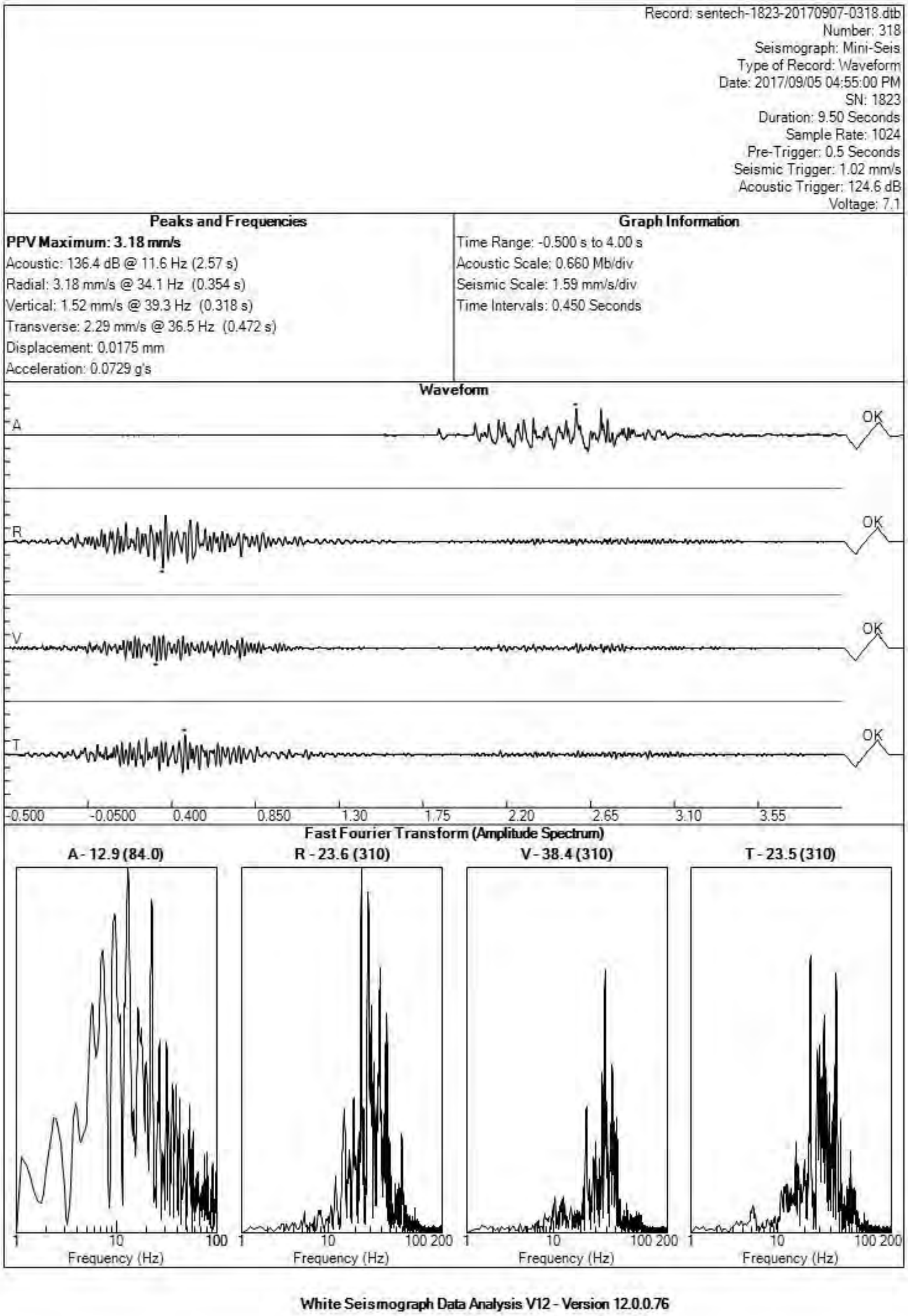
Persson, P-A, Holmberg, R and Lee, J, 1994, *Rock Blasting and Explosives Engineering*. CRC Press, USA.

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 2 (cont): Vibration and Airblast Limits.



<u>Appendix 3</u>: Vibration and Airblast Data plotted against the USBM Standard.



<u>Appendix 3 (cont)</u>: Vibration and Airblast Data plotted against frequency.