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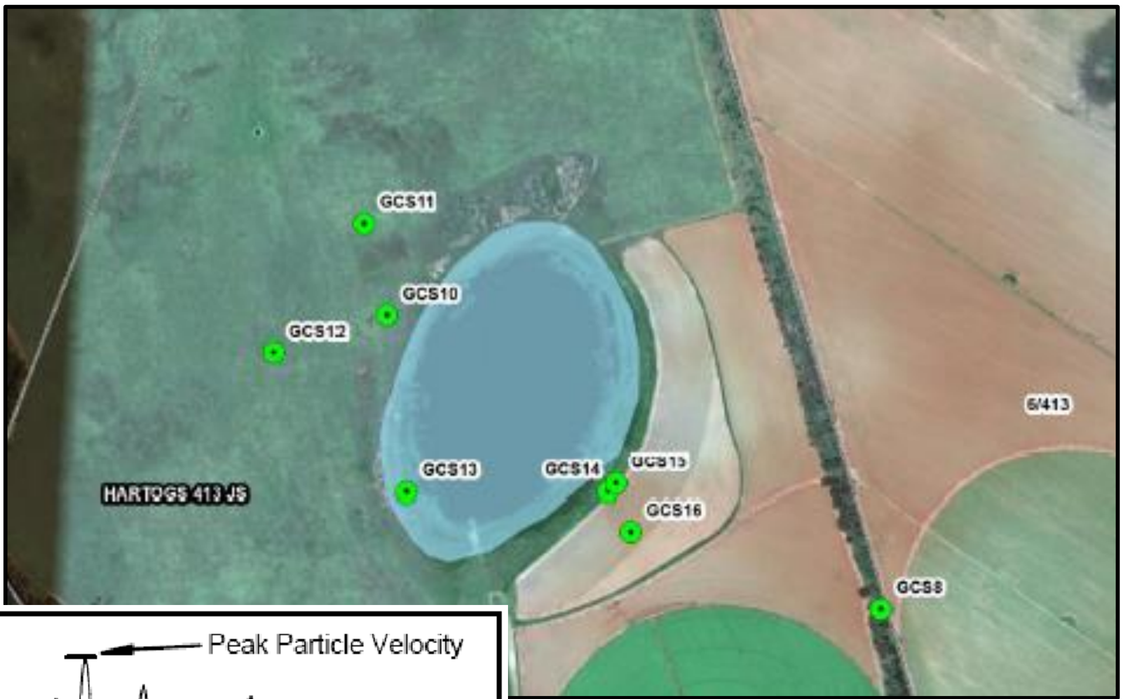
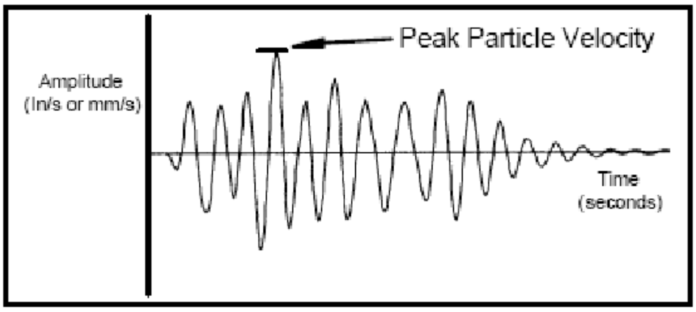
ECO ELEMENTUM – NNDANGANENI COLLIERY – BLAST AND GROUND VIBRATIONS STUDY





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1. INTRODUCTION

The Junior Environmental Consultant (Lian Roos) requested Big C Rock Engineering to conduct a desktop blasting and vibration study as part of their client's proposed Section 102 application to expand the existing Mining Right 299MR at Nndanganeni Colliery. The mining operation follows opencast drill and blast methods.

2. BACKGROUND

2.1. LOCATION

The proposed extension area is located approximately 26km East from the town of Middelburg on the farm Hartogshof 413 JS in the Mpumalanga province. The location of the proposed mining area is illustrated with a star in Figure 1. The mining area is located adjacent to the N4 Public Road, which runs parallel with the R104.

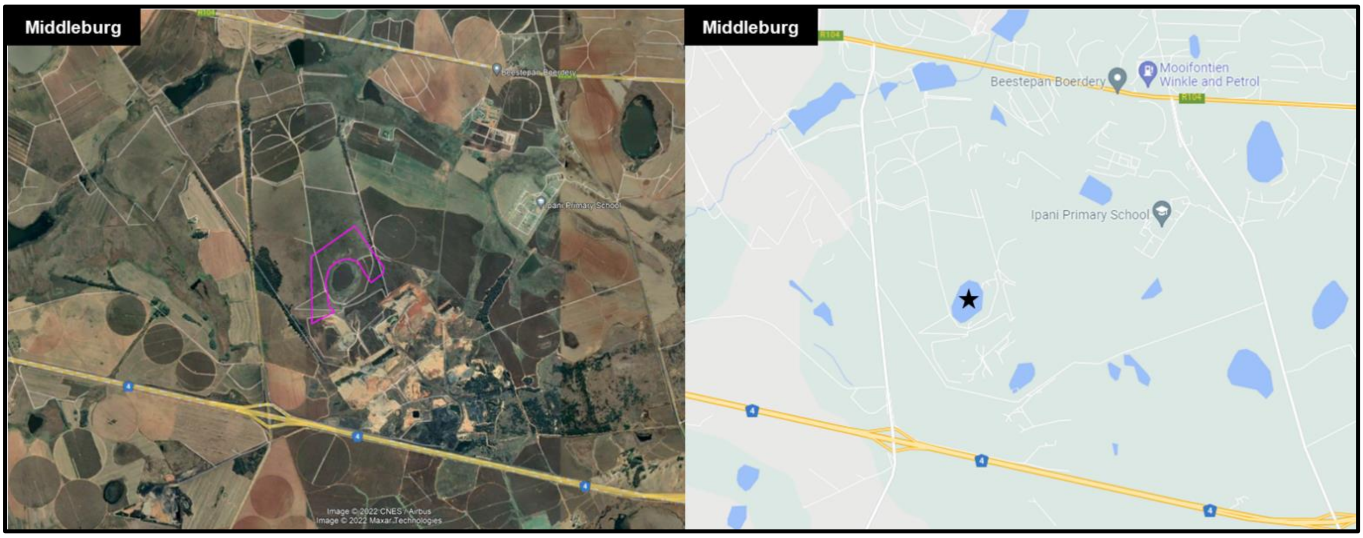


Figure 1: Location of the mining right area

2.2. SENSITIVE RECEPTORS

The sensitive receptors for the proposed mining area include all surface structures noted in Regulation 4.16 (2) of the Mine Health and Safety Act of 1996 which states that:

No blasting operations are carried out within a horizontal distance of 500 meters of any public building, public thoroughfare, railway line, power line, any place where people congregate or any other structure, which it may be necessary to protect in order to prevent any significant risk, unless:

a) A risk assessment has identified a lesser safe distance and any restrictions and conditions to be complied with;

b) *A copy of the risk assessment, restrictions and conditions contemplated, in paragraph (a) have been provided for approval to the Principal Inspector of Mines;*
c) *Written permission has been granted by the Principal Inspector of Mines; and*
d) *Any restrictions and conditions determined by the Principal Inspector of Mines are complied with.*

The proposed extension area is located in an area where mining has been part of for several years. Sensitive receptors include farm roads, a pan, existing opencast workings etc.

2.3. GEOLOGY

The mining area falls within a sedimentary (*Sedimentary rock has the distinct identification characteristic of being bedded*) environment of the Witbank Coalfield located in the coal bearing strata hosted in the Vryheid Formation of the Ecca group of the Karoo Supergroup. The Witbank Coalfield has several seams that are available for exploitation. The mining environment generally consists of horizontally stratified sedimentary rocks with occasional igneous (*Igneous rocks are rocks that have solidified from molten material known as magma or lava*) intrusions.

The site-specific area is characterized by shale, shaley sandstone, grit sandstone, conglomerates and coal. A percussion drill log of borehole GCS16 from the mining area is illustrated in Figure 2, illustrating the strata composition of the mining area. The drill log was extracted from the Hydrogeology report of the mining area (GCS Reference number 15-541).

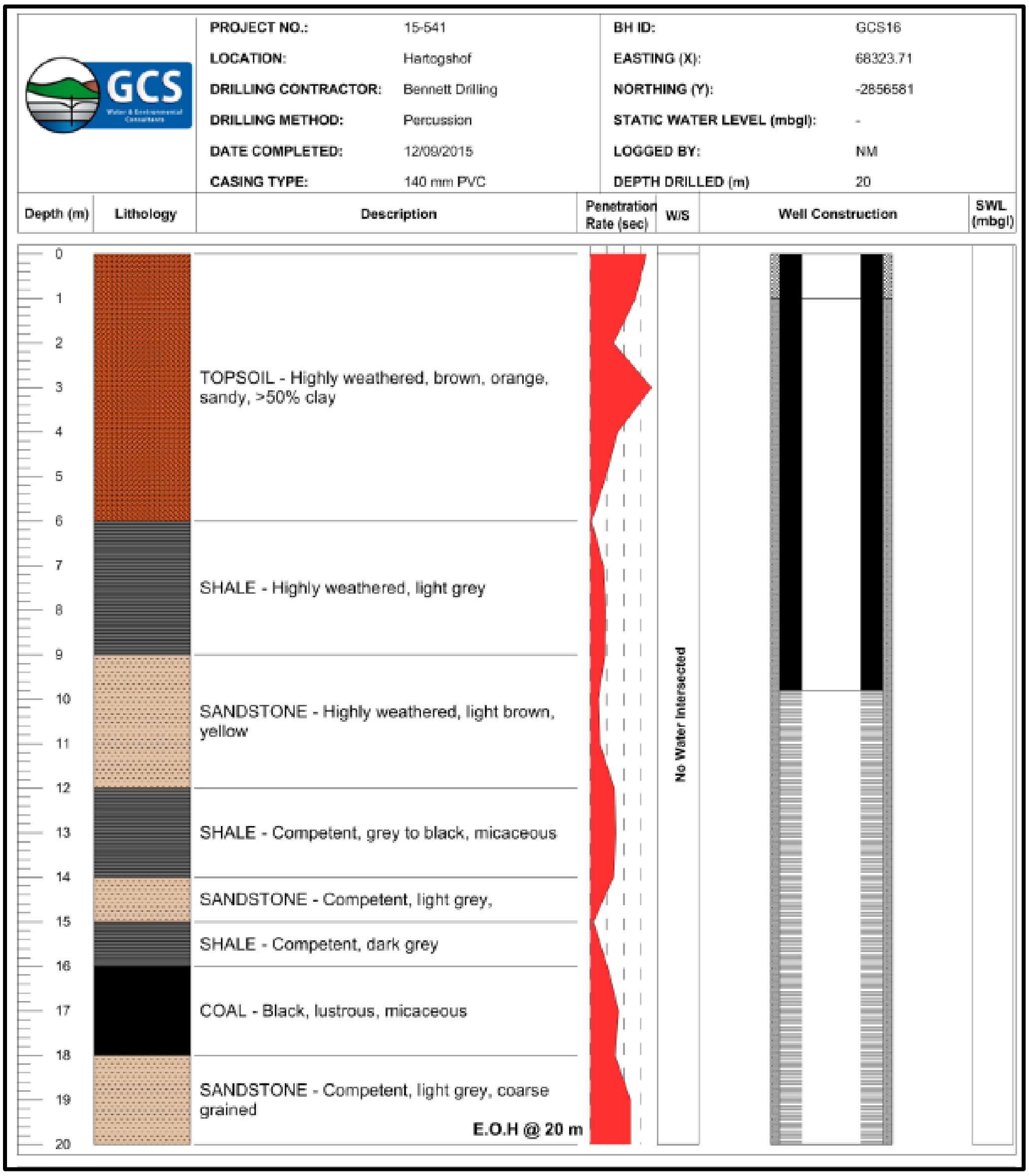


Figure 2: Illustration of drill log GCS16

Geotechnical conditions that can be expected in the mining area is:

- Soft overburden consisting of soils and weathered strata material, overlaying the hard rock sedimentary strata material followed by several coal seams and sedimentary partings.
- Frequent horizontal jointing/bedding planes which forms part of the nature of sedimentary rocks.
- Occasional jointing with irregular dip and strike.
- Occasional igneous intrusions in the form of dykes or sills.

3. GROUND VIBRATIONS ASSESSMENT

In the opencast mining environment explosives are used to break rock into smaller loads and haulable fragments through the shockwaves and gases generated from the explosion. Ground vibration is a natural result from blasting activities. The far field vibrations (*those vibrations felt further away from the blast area*) are inevitable, but undesirable by-products of blasting operations. The shockwave energy that travels beyond the zone of rock breakage is wasted and could cause damage and annoyance further on. The magnitude of the shockwave is determined by the following factors (Rangasamy, 2018):

- The charge mass per delay,
- The delay period,
- Distance from the blast,
- Rock mass and
- Geometry of the blast.

The factors influencing ground vibrations that can be controlled by a planned design and proper blast preparation, are as follows (Rangasamy, 2018):

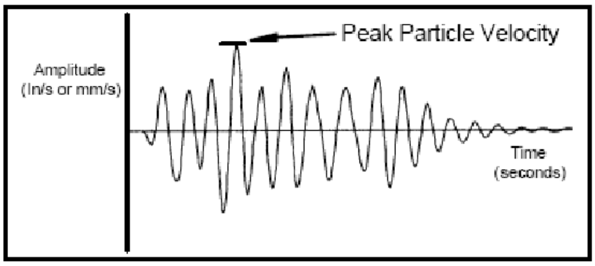
- *The larger the charge mass per delay the greater the vibration energy yielded*. When a number of holes are detonating simultaneously the maximum total explosive mass per such delay will have the greatest influence on the amount of ground vibrations. In practice, this means that if all holes are detonated individually, the weight of explosives per single hole is considered as opposed to the entire mass if multiple holes are detonated. Therefore, if more than one hole is detonated simultaneously, the mass per hole for each hole must be added up. Specifically, charges detonated within 15 milliseconds are considered as a single detonation, and delays of more than 15 milliseconds are treated as separate blasts.
- *The distance between the blast and the point of interest*. The ground vibrations weaken over distance at a rate determined by the mass per delay, timing and geology. Each geological interface (slips, joints, discontinuity planes, etc.) that a shockwave encounters will reduce the vibration energy, due to reflections of the shockwave. In rock such as sedimentary or laminated material with high laminations and with multiple bedding planes the shockwave transfer will be limited.
- *The geology of the blast medium and surroundings* also influences the magnitude of vibrations. High density materials have high shockwave transferability, whereas low density materials have lower transferability of the shockwave. For example, when comparing coal (density of 14-16 kN/m^3) and granite (26 to 27kN/m^3), granite will be the better conductor of the shockwave.

3.1. GROUND VIBRATIONS FORMULA

In order to assess or predict the effect of a blast and the resultant ground vibration in the proposed mining area, the Peak Particle Velocity calculations will be used to determine the effect that it may have on the geology and surrounding surface structures. The most widely accepted measurement of ground vibrations is the Peak Particle Velocity (PPV) during which a standard accepted mathematical process of scaled distance is used:

peak particle velocity calculation Where: y – *peak particle velocity (mm/s)* a – *site constant* b – *site constant* ***D*** – *Distance* ***E*** – *Explosive mass or Charge per Delay*	$y = a\left(\frac{D}{\sqrt{E}}\right)^b$

The PPV is the maximum ground motion amplitude experienced by a particle subjected to ground vibration or is defined as the speed at which a particle of ground/soil vibrates as the wave passes through a particular section. PPV is measured in meters per second (m/s) or millimetres per second (mm/s).



Since site-specific tests have not been conducted for the mining area the following conservative industry accepted constants will be used and is applied for the prediction of ground vibration (Rangasamy, 2018):

a – *1143*

b – *-1.65*

Note that site-specific blasting designs have also not yet been conducted, therefore the calculations referred to in this report will serve as a guideline from which site-specific blast designs can be drafted once mining commences.

When considering the PPV values it must be noted that different structures behave differently and therefore the PPV levels are described below for the criteria of the different structures:

- Rock Breaking
- Underground workings (if mining will be conducted in close proximity to underground workings)
- Surface structures such as Eskom, Public roads, pipelines and conveyors.
- Different types of buildings

3.2. VIBRATIONS LIMITING CRITERIA

3.2.1. GROUND VIBRATIONS LIMIT CRITERIA – ROCK BREAKING

The ground vibration problems developed because of the peak particle velocity which is necessary to break the rock and can be classified in the following broad bands when considering rock breaking (Thompson, 2005):

PPV (mm/s)	**Classification description**
<250 mm/s	No fracture of rock
250 - 525 mm/s	Tensile stress failure of rock
525 - 2500 mm/s	Tensile stress failure and radial cracks form
>2500 mm/s	Fragmentation of rock

3.2.2. GROUND VIBRATIONS LIMIT CRITERIA – UNDERGROUND WORKINGS

According to Van Wijk (2001) most studies that deal with the effects of opencast blasting concentrate on the damage to surface structures (mostly buildings) during which the most severe damage to structures is caused by blast vibration frequencies in the order of 14Hz. Van Wijk further found that the PPV's up to 125 mm/s will not adversely affect future underground mining.

When considering underground workings, the following guidelines are set apart in terms of damage to the underground workings (Oriard, 1972):

PPV Level	Cause
< 50 mm/s	Negligible effects on underground workings
50 to 100 mm/s	Will cause loose rock to fall underground
130 to 380 mm/s	Will cause partially loosened rock underground and on surface slope to fall
> 635 mm/s	Will cause damage to intact rock

3.2.3. GROUND VIBRATIONS LIMIT CRITERIA – SURFACE STRUCTURES

South African legislation does not specify the maximum allowable ground vibration limits. However, several studies within South Africa have investigated vibration limits. The vibration limits suggested by Rorke (2011) for civil and engineering structures will be used in this report (Table 3):

Structure	PPV mm/s limit	Description
Eskom Power Lines	<75 mm/s	Conservative value since the steel structure of pylons and concrete foundation blocks can both withstand significantly higher values.
Public Roads	<150 mm/s	Desegregation of road material will start to appear at vibration amplitudes above 150mm/s
Pipelines (water and Transnet)	<50 mm/s	Blasting near pressurized steel pipelines has taken place safely at PPV's of >50 mm/s in South Africa.
Conveyors	< 200mm/s	A steel conveyor structure will withstand very high vibrations and the concrete plinths will remain undamaged by ground vibrations up to 200mm/s.

3.2.4. GROUND VIBRATIONS LIMIT CRITERIA – BUILDINGS

Furthermore, the United States Bureau of Mines (Siskind et al, 1980) Criteria is used for civil infrastructure such as buildings and houses (Table 4):

Type of Building	Ground vibration limit
General houses of proper construction	25 mm/s
Houses of lesser proper construction	12.5 mm/s
Rural buildings	6 mm/s

3.3. PREDICTED GROUND VIBRATIONS

The outcome of the PPV calculations is illustrated below for different structures. The following notes are made on the outcomes:

- It can be seen that a higher charge per delay results in increased PPV outcomes.
- The distance from the surface structures also influences the PPV outcomes significantly.
- When using high charge weights (more than 300kg) structures in close proximity (50m or less) will be significantly affected – refer to the red area on the table.
- Low charge weights in combination to increased distance will be preferred.

Structures	Distance (m) D									
Charge per Delay (Kg) E	50	100	150	200	250	300	350	400	450	500
100	80	26	13	8	6	4	3	3	2	2
150	112	36	18	11	8	6	5	4	3	3
200	142	45	23	14	10	7	6	5	4	3
250	171	54	28	17	12	9	7	6	5	4
300	199	63	32	20	14	10	8	6	5	4
350	226	72	37	23	16	12	9	7	6	5
400	252	80	41	26	18	13	10	8	7	6
450	278	89	45	28	20	14	11	9	7	6
500	303	97	49	31	21	16	12	10	8	7
550	328	104	53	33	23	17	13	11	9	7
600	352	112	57	36	25	18	14	11	9	8

PPV	Description
<50mm/s	Pipelines
<75mm/s	Eskom Power Lines
<150mm/s	Public Roads
<200mm/s	Conveyors
>200mm/s	too high for structures

Outcome – Opencast PPVs, Charge per delay versus distance from blast

3.4. MITIGATING MEASURES

Ground vibrations are the unfortunate, unavoidable side effect of blasting, however ground vibrations can be limited by implementing mitigating measures such as recommend by Thompson, 2005:

- Small amount of explosive charge per delay should be used when blasting in close proximity to sensitive receptors.
- The delays between the rows must not strengthen the shockwave, i.e., single hole firing with electronic detonators.
- Blast parallel to the main joint set or geological discontinuities (dolerite dyke intrusions, slips etc.).
- Use a pre-split or other highwall control drilling method to isolate the main blast-block from the rest of the rock mass, i.e., create a second free face.
- Electronic, single hole firing is the preferred method to reduce the amount of explosive charge per delay.

4. AIR BLAST ASSESSMENT

Air blast represents an undesirable and unavoidable output of the blasting technique. Air blasts can also be referred to as 'air – overpressure'. The air blast damage and annoyance can be influenced by various different factors such as the blast design itself, the weather, field characteristics and human response (Aloui et al, 2016). An air blast disturbance propagates as a compression wave in the air.

Air blasts are often confused with sound that is within an auditable range. According to Thompson (2005), air blasts are the cause of most complaints regarding blasting since the public apt to confuse air blasts and ground vibrations with one another. Aloui et al (2016) indicates that the audible part of an air blast is characterized by higher frequencies from 20 to 20 000Hz whilst the sub-audible part of the air blast has low frequencies of below 20 Hz. *The audible part of an air blast is called noise* whilst the frequencies below 20 Hz is called as concussion and classified as *"over pressure" when the air blast pressure exceeds atmospheric pressure*. It is the over pressure that exerts a force on structures and in turn causes a secondary and audible rattle within a structure.

The following guidelines for air blasts in South Africa are set apart Brovko et al. (2016):

Decibels	Effect
100	Barely noticeable
110	Readily acceptable
120	Currently accepted by South African authorities as being a reasonable level for public concern.
134	Currently accepted by South African authorities that damage will not occur below this level.
150	Windows break
176	Plaster cracks
180	Structural damage

Since air blasts damage and annoyance can be influenced by various different factors, it is recommended that a well-balanced conceptual design be generated as to not generate significant air blast. Controls such as the following should be considered during the design process (Thompson 2005):

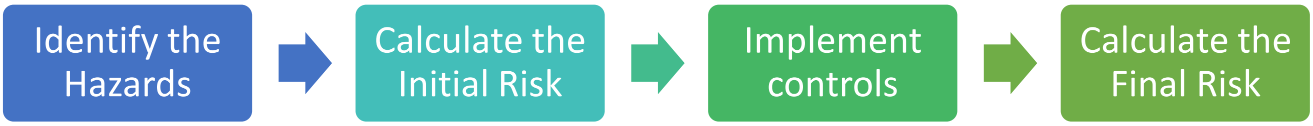
- Cover all detonating cord or use noiseless shock tube or electric trunk lines.
- Limit explosives per delay
- Blasting should not be conducted early in the morning because of temperature inversion
- Blasting should not be conducted when the wind is very strong
- Blast ideally at peak noise time
- Avoid short collars and fill blast holes with enough stemming.

5. RISK ASSESSMENT – GROUND VIBRATIONS AND AIR BLAST

The risk assessment conducted for the purpose of this report focuses on the effect of ground vibrations on the highwall and surrounding surface structures. The mining environment is heterogenous (*diverse in characteristics and phases*), conditions change from one mining block to the next and it may be that not one blast is similar to the next. It is for this reason that controls must be implemented as hazards occur and monitoring must be conducted throughout the process to continuously update and optimize the mining process.

5.1. RISK ASSESSMENT PROCESS

The risk assessment process is illustrated in Flow diagram 2.



Flow diagram 2: Risk Assessment Process

5.2. RISK MATRIX

The risk matrix that will be used to calculate the initial and final risk is illustrated below in Table 2. The risk can be calculated by using the following calculation:

Risk (R) = Probability (P) x Consequence (S) x Exposure (E)

Probability (P)	Certain that it will occur	5
	Likely that it will occur	4
	Possible that it will occur	3
	Rare that it will occur	2
	Very unlikely that it will occur	1
Severity (S)	Minor property loss	1
	Causing multiple injuries or property loss that result in production loss for the neighbouring party	2
	Causing fatalities to at least 1 person and or damage to equipment of less than R1 mil	3
	Causing multiple fatalities and or significant property loss of more than R1 mil	4
	Causing fatalities, injuries or significant damage to neighbouring properties and civilians resulting in the production and money loss in the macro environment.	5
Exposure (E)	Continuous exposure	5
	Frequent exposure	4
	Occasionally exposed	3
	Rarely exposed	2
	Very rarely exposed	1
Risk Level	High risk – high probability of occurring, immediate action needed	>60
	Substantial Risk – medium probability of occurring action needed.	>40-60
	Low Risk – low probability of occurring	0-40

Risk Matrix

5.3. RISK ASSESSMENT

A risk assessment was compiled based on the risk matrix and flow diagram process described above. The risk assessment is illustrated below:

Baseline Risk Assessment – Blasting in close proximity to Surface Structures (Various)										
Hazards	Hazard Consequences	Initial Risk Value				Eliminate → Control → Minimize → PPE → Monitor	Final Risk Value			
		P	S	E	R		P	S	E	R
Ground Vibrations as a result of blasting	Excessive ground vibrations resulting in damage to surface structures	5	5	5	125	1. Appoint a qualified blaster as per Chapter 4 of the MHSA of 1996 to conduct a proper blast design for each and every mining block that will be blasted. 2. Appoint a surveyor to identify all surface structures located in close proximity to the mining area as per regulation 17.2 (a) of the MHSA of 1996. 3. Ensure that a blasting code of practice is compiled site specific to the mining area which must ensure that the ground vibrations caused by blasting is limited as far as practical possible for each mining block and its associated sensitive receptors. 4. Limit ground vibration to an acceptable value with a proper blast design, measure and record, evaluate and improve. 5. Limit blasting distance in close proximity to structures to 500m unless specialist studies based on risk assessments is conducted and permission granted by the Principal Inspector of Mines to blast within 500m of surface structures.	2	5	2	20
Air Blasts as a result of blasting	Excessive air blasts resulting in fly rock and damage to surface structures	5	5	5	125	1. Appoint a qualified blaster as per Chapter 4 of the MHSA of 1996 to conduct a proper blast design for each and every mining block that will be blasted. 2. Appoint a surveyor to identify all surface structures located in close proximity to the mining area as per regulation 17.2 (a) of the MHSA of 1996. 3. Ensure that a blasting code of practice is compiled site specific to the mining area which must ensure that the ground vibrations caused by blasting is limited as far as practical possible for each mining block and its associated sensitive receptors. 4. Limit the decibels to an acceptable value with a proper blast design, measure and record, evaluate and improve. 5. Limit blasting distance in close proximity to structures to 500m unless specialist studies based on risk assessments is conducted and permission granted by the Principal Inspector of Mines to blast within 500m of surface structures.	2	3	2	12

6. CONCLUSION

This report contains the assessment of ground and air vibrations and gives the applicable limits which forms part of the baseline assessment for blasting. Once mining commences a proper operational blast design and code of practice must be compiled, implemented, monitored, evaluated and improved.

7. REFERENCES

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