Blast Management & Consulting

Report:
Blasting Assessment Study
For Northern Coal (PTY) Ltd,
Weltevreden 381JT Portions 15 and 16 Project
Dated 28 September 2008

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Contents

1. Executive Summary

The expected ground vibration and airblast levels from blasting operations required at the Northern Coal (PTY) Ltd Portion 15 and 16, farm Weltevreden 381JT project was calculated and considered in relation to the surrounding structures and installations. Some concerns were identified from review of the expected ground vibration and air blast levels. These concerns are however manageable and in no way such that blasting should be prohibited. The main concerns are related to distance between the mining area and the nearest structures – House 14 & 15 specific. Expected levels of ground vibration and airblast are within the allowed limits but levels are such that it could be perceptible. This in turn may lead to complains and subsequent investigations. Ground vibration levels at the closest houses are 10 and 19.9 mm/s respectively for the largest charge mass applied. Considering the reduced charge modelled, this will have a decreased ground vibration effect and reduce the risk significantly. This is within the general safety limit of 25 mm/s. All other structures / installations were well within limits with no significant effect. Mitigation in reducing the maximum charge mass per delay and design of blasts in the areas of house 14 & 15 will assist to control the ground vibration.

Airblast levels reviewed showed no direct concern with regards to damage to structures, but did indicate that mitigation of the ground vibration will also bring about reduced airblast levels. Maximum level observed was 126 dB at the nearest house. This is within accepted norm of 134dB. Reduced charges and control on stemming will be assisting in reducing the possibilities of complaints from home owners.

This report summarises the evaluation of expected effects from blasting operations in the new Weltevreden 381JT project. It is concluded that blasting will be possible but careful consideration should also be given to the recommendations made.

2. Introduction

Northern Coal (PTY) Ltd is proposing the development of an opencast mining operation of the coal deposit located under Portion 15 and 16 of the farm Weltevreden 381JT. The farm is located on the South West corner of the junction of the N4 highway and the R33. This junction is 5km south west of the town Belfast, in Mpumulanga. The applicable Magisterial District is Belfast, Mpumulanga. Latitude and Longitude: 25º 43min 0sec South 30º 03min 0sec East.

Blast Management & Consulting was contracted to perform an initial desktop review of possible impacts with regards to blasting operations due to the mining operation.

This study reviews possible influences that blasting may have on the surrounding area of the opencast mining area. A typical drill and blast design is used as guideline for ground vibration and air blast related effects from blasting operations.

This report covers mainly the expected ground vibration and air blast, but will also address aspects of fly rock, fumes and general safe blasting considerations.

3. Protocols and Objectives

The protocols applied in this document are based on the author's experience, guidelines from literature research, client requirements and general indicators from the various acts of South Africa. There is no direct reference in the following acts with regards to requirements and limits on the effect of ground vibration and air blast specifically and some of the aspects addressed in this report. The acts consulted are: Minerals act, Exploration act, Mine Health and Safety Act, Mineral and Petroleum Act National Environmental Management Act 107 of 1998. However it is sure that the protocols and objectives will fall within the broader spectrum as required by the various acts.

The objective of this document is to outline the expected environmental effects that blasting operations could have on the surrounding environment. This study investigate the effect of blasting operations and the related influences with regards to expected ground vibration, air blast, fly rock, and noxious fumes. These effects are investigated in relation to the surroundings of the blast site and possible influence on the neighbouring houses and owners or occupants.

Objectives can be summarized according to the following steps taken as part of the EIA study with regards specifically to Ground Vibration and airblast due to blasting operations by Blast Management & Consulting.

1 Visualisation of the Proposed Site:
2 Blasting Requirements:
3 Ground Vibration and Prediction
4 Limitations on Structures
5 Limitations with regards to Human perceptions
6 Air blast and Prediction
7 Fly Rock
8 Noxious Fumes
9 Site Specific Recommendations: Specific attention is then given to the site and discussed in particular to the following aspects:
9.1 Ground vibration and Human Perception
9.2 Air blast
9.3 Fly-Rock
9.4 Noxious Fumes
9.5 Blast Initiation
9.6 Safe Blasting Procedures
9.7 Monitoring
9.8 Risk Assessment

4. Visualisation of the Proposed Site

The Weltevreden farm is located on the South West corner of the junction of the N4 highway and the R33. This junction is 5km south west of the town Belfast, in Mpumulanga. The applicable Magisterial District is Belfast, Mpumulanga. Latitude and Longitude: 25º 43min 0sec South 30º 03min 0sec East.
Figure 1 shows an aerial view of the planned project area with surroundings. Figure 2 shows a plan provided with mining area and surroundings.

The site was reviewed and presented hereafter. Site was reviewed / scanned using Google earth imagery and information provided by Digby Wells & Associates. Information sought from review was typically what surface structures are present in a 4400m radius from the proposed mine boundary that will require consideration during modelling of blasting operations. This could consists of houses, general structures, power lines, pipe lines, reservoirs, mining activities, roads, shops, schools, gathering places, possible historical sites etc. A list was prepared for the type of surface structures and direction from the mine operation position. This is required for determining the allowable ground vibration limits, air blast limits and possible wind direction constrains that might be applicable. The surface structure concerns are provided in table 1 & 2 below. Graphical Visualisation of mining operation and the expected ground vibration and airblast levels is presented on figures and is supplied in the discussion section. Due to the fact that no design is available yet for such a mine operation, the maximum depth was used as guideline for determining the expected charge size. Detail of typical design is provided in the discussion.

Figure 1: Aerial View of Project Area.

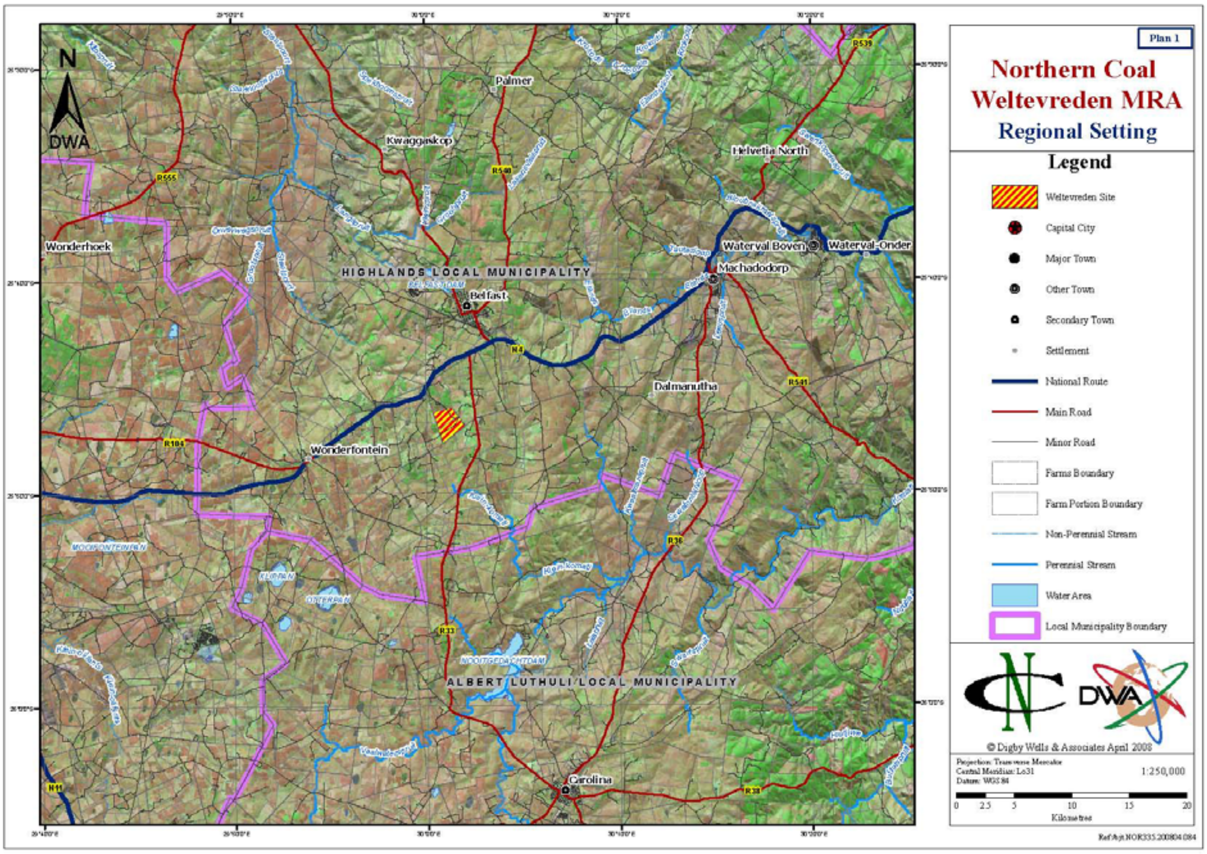
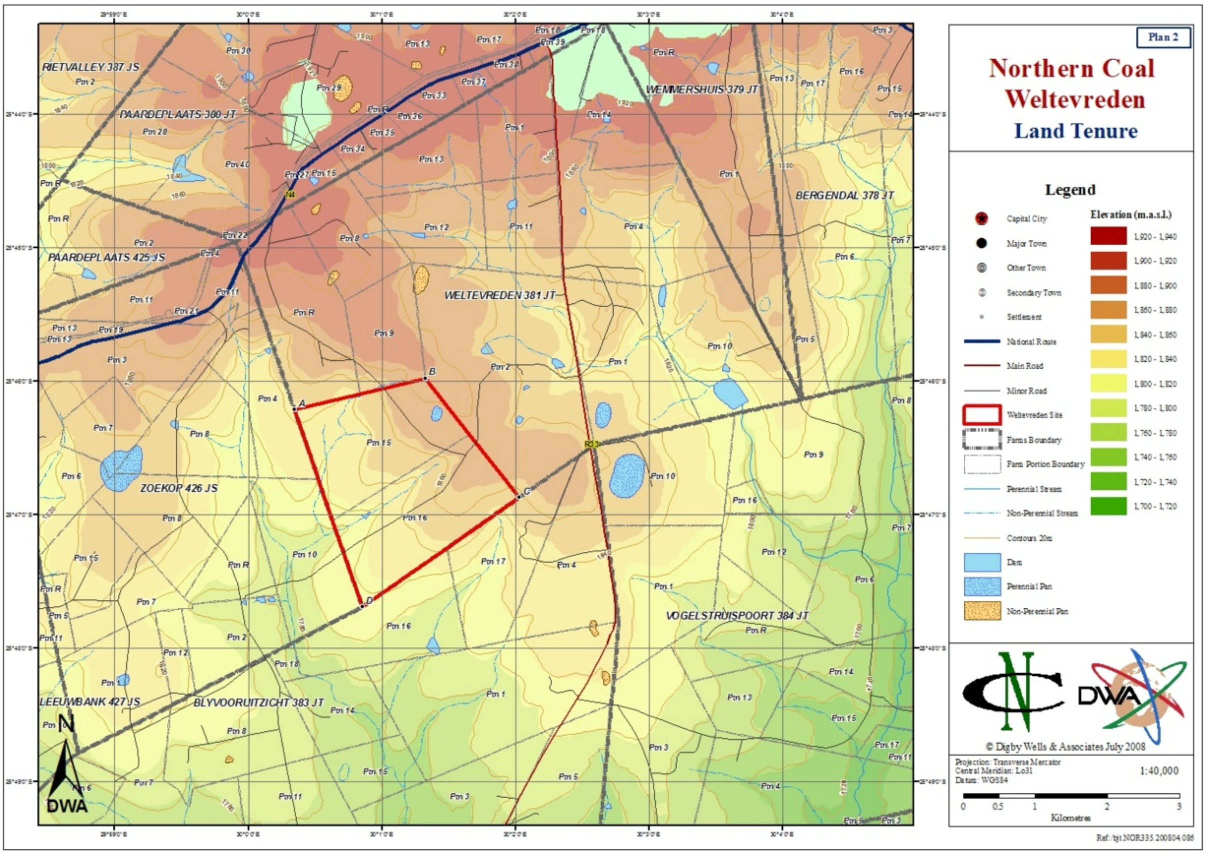


Figure 2: Surface Plan Of the project area.



4.1 Visualisation of the Proposed Sites

The proposed mining operation location was reviewed and a list of surface structures was identified surrounding the mine area. Table 1 below is a list of all the farmers surrounding the mining area and table 2 shows a list of the farmer's structures / farmsteads that was used for review in this document.

Table 1: Farms and farmers surrounding the mining area.

Farm	Name of Farmer/Owner	Tel
Portion 8 – Zoekop	Kowie Gerrits	083 771 1820
Portion 4 – Weltevreden	Bernard Green	079 477 3146
Portions 4 & 17 – Blyvooruitzicht	Ben Kotzé	082 561 6934
Portion 1 – Weltevreden	Morris Schupe	082 707 4807
Portions 3, 13, 15 Vogelstruispoort	Hendrik Griffiths	082 553 2388
Portion 3 – Blyvooruitzicht	Petrus Badenhorst	082 443 3086
Portion 1 – Blyvooruitzicht	Pierre de Villiers	082 770 6141
Portion 4 – Vogelstruispoort	Nico Kriek	083 449 6806
Portion 15 – Zoekop	Chris Botha	013 253 1053
Portion 10 Vogelstruispoort & Portion 10 Weltevreden	Gary de Bruin	082 338 5114
Portion 4 – Zoekop	André Viljoen	083 625 5157
Portions 8, 9 & R of Weltevreden	Sameul Lundall	082 892 2417
Portion 1 – Vogelstruispoort	Jan Potgieter	072 725 2070
Portion 1 – Zoekop, Portion 16 Blyvooruitzicht	Willie Pretorius	083 388 4371
Portions 15, 16 & 2 – Weltevreden	Therésilda Lotter	084 250 3300
Portion 5 – Blyvooruitzicht	Charles Griffiths	082 563 5905
Portion 10 – Zoekop	Koos Pretorius	083 986 4400

Table 2: Structures / Farmsteads identified for consideration.

No.	Structure	Direction from Pit Position	Shortest Distance (m)
1	House01	SE	1676
2	House02	SE	2595
3	House03	SE	1021
4	House04	NE	3667
5	House05	NE	2303
6	House06	SW	4342
7	House07	NE	2681
8	House08	NE	2681
9	House09	NE	2016
10	House10	NE	3708
11	House11	SW	3890
12	House12	W	2656
13	House13	NW	1904
14	House14	SE	810
15	House15	SW	534
16	House16	NE	1028
17	House17	NE	2746
18	House18	SW	2344
19	House19	W	2786
20	House20	E	989

5. Blasting Requirements

The mining operation has not yet been detailed in blasting plans and expected drill and blast procedures. Considering the geological report provided estimates were taken of min and maximum over burden depths to be considered for blasting. The geological report indicates that overburden above coal ranges between the 4.3 and 25.9m depths. *See Report: Exploration Report 14-4-2008.* As a guide the values of 15 and 25 m overburden depth was used in calculations. Basic designs were done (see table 3) that incorporate these expected overburden levels and these designs used for determining the required charge mass per delays for ground vibration and airblast modelling. Calculations used in this document are based on the typical designs provided below.

Table 3: Information on possible blast designs to be used.

Aspect	15m Bench	25m Bench
B/H Diameter (mm)	165	165
a - B:S Ratio	1.15	1.15
Fly rock Factor	1.5	1.5
Explosive Density (g/cm^3)	1.15	1.15
Burden (m)	4	4.6
Spacing (m)	5	5.3
Bench Height (m)	15	25
Min Depth (m)	15	25
Air gap (m)	0	0
Average Depth (m)	15	25
Linear Charge Mass (kg)	24.59	24.59
P/F Blasthole (kg/m$^{3)}$	0.93	0.86
Stemming Length (m)	4.95	4.95
Column Length (incl. Sub drill.)	11.4	21.4
Explosives Per B/H (incl. Sub drill+air gap) (kg)	280	525.5

Sub-drill (m)	1.32	1.32
Ratio: Burden: Bench Height	3.8	5.4
Max. Blasthole Depth (m)	16.3	26.3

The two basic models considered during the evaluation process are both 165mm diameter blasthole sizes with different depths used as option 1 and option 2. There is a significant difference in the resultant charge mass per blasthole between the two depths. A further consideration used is the type of initiation system used. A typical shock tube system is considered with the 165mm diameter blasthole. This will typically result in 4 blastholes detonating simultaneously and on the deeper blasthole will yield a maximum charge 2102 kg. This mass was used as a worst case scenario. The use of an electronic initiation system can reduce the quantity of blastholes detonating to a single blasthole. A single 165 mm diameter blasthole at 25 m depth will yield 526kg charge and a single 165 mm diameter blasthole 15m deep will yield 280kg. In all cases it is based on the depths and stemming lengths as per table above.
(Please note that original modelling took a sub drill into account which should not be considered, as drilling will only be to top of coal. This will make the explosives used less than predicted.)

6. Ground Vibration and Prediction

Explosives are used to break rock through the shock waves and gasses yielded from the explosion. Ground vibration is a natural result from blasting activities. The far field vibrations are inevitable, but un-desirable by products of blasting operations. The shock wave energy that travels beyond the zone of rock breakage is wasted and could cause damage and annoyance. The level or intensity of these far field vibration is however dependant on various factors. Some of these factors can be controlled to yield desired levels of ground vibration and still produce enough rock breakage energy.

Factors influencing ground vibration are the charge mass per delay, distance from the blast, the delay period and the geometry of the blast. These factors are controlled by planned design and proper blast preparation.
The larger the charge mass per delay – not the total mass of the blast, the greater the vibration energy yielded. Blasts are timed to produce effective relief and rock movement for successful breakage of the rock. A certain quantity of holes will detonate within the same time frame or delay and it is the maximum total explosive mass per such delay that will have the greatest influence. All calculations are based on the maximum charge detonating on a specific delay.

Secondly is the distance between the blast and the point of interest. Ground vibrations attenuate over distance at a rate determined by the mass per delay, timing and geology. Each geological interface a shock wave encounters will reduce the vibration energy due to reflections of the shock wave. Closer to the blast will yield high levels and further from the blast will yield lower levels.

Thirdly the geology of the blast medium and surroundings has influences as well. High density materials have high shock wave transferability where low density materials have low transferability of the shock waves. Solid rock i.e. norite will yield higher levels of ground vibration than sand for the same distance and charge mass. The precise geology in the path of a shock wave cannot be observed easily, but can be tested for if necessary in typical signature trace studies – which are discussed shortly below.

Normally, in order to determine effective control measures, it will be required to do signature hole trace study. This process consists of charging and blasting test holes that are measured for ground vibration and air blast at various distances. Signature trace data can then be used to determine site specific constants for prediction of ground vibration and assist in determining timing of blasts in order to minimize the effect of vibration.

6.1 Prediction of Ground Vibration

When predicting ground vibration and possible decay, a standard accepted mathematical process of scaled distance is used. The equation applied (Equation 1) uses the charge mass and distance with two site constants. The site constants are specific to a site where blasting is to be done. In new opencast operations a process of testing for the constants is normally done using a signature trace study in order to predict ground vibrations accurately and safely. This is done by firing single holes at the site in question and monitoring the ground vibrations at various distances. The peak particle velocity (PPV) or ground vibration in mm/s is plotted against the scaled distance (D/√E) on a log/log graph. From this graph the slope and y-intercept for the trend line through the points are determined. The site constants *a* and *b* are your y-intercept and your slope of the trend line respectively. The utilization of this formula is standard practice. The analysis of the data will also give an indication of frequency decay over distance.
In the absence of a signature trace study there is however constants used prior to actual tests which will take most of the factors into account. The signature trace process can be applied and will be useful in long term mining on surface and in sensitive blasting areas.

Equation 1:
$y = a(D/\sqrt{E})^b$
Where:
y = Predicted ground vibration
a = Site constant
b = Site constant
D = Distance
E = Explosive Mass

In the absence of tested values for a & b the following factors are normally used and applied for prediction of ground vibration. It is also these factors that were applied for predicting expected ground vibrations in the area for the blasting to be done at the mining area.

Factors:
a = 1143
b = -1.65

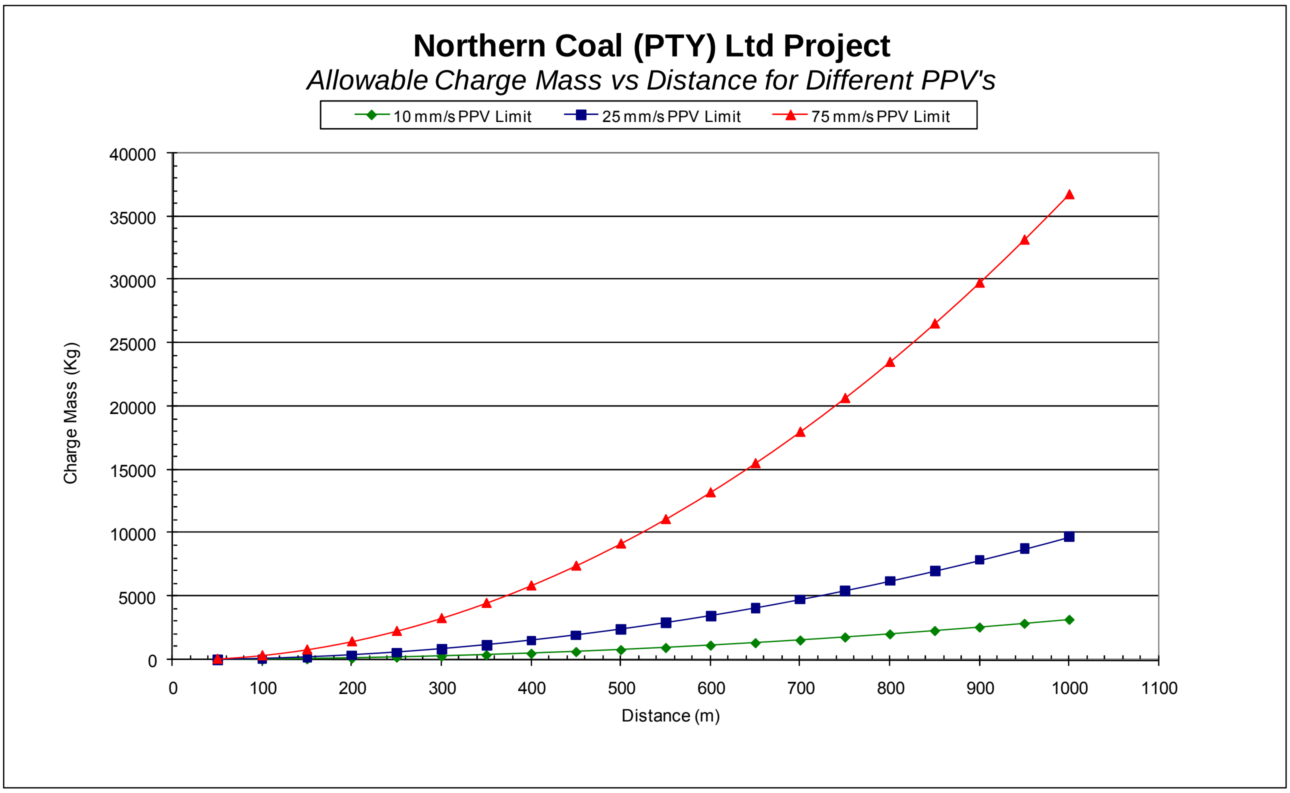
Utilizing the abovementioned equation and the given factors, allowable levels for specific limits and expected ground vibration levels can then be calculated for various distances.
Review of the type of structures observed around the mine operation and the limitations that may be typically applicable indicated that three different levels of ground vibration are necessary to consider. These are the 10 mm/s, 25 mm/s and 75 mm/s levels. The blast design considered showed that the maximum charge per delay expected on a worst case scenario could be 2102 kg. Considering the parameters, ground vibration and charge mass, the following calculations were done for consideration in this report.
Firstly the distance required from specific charge masses to maintain different vibration limits (10mm/s, 25 mm/s and 75 mm/s) was calculated and presented in Table 4 below. The charge masses used are representative of minimum and maximum charges that can be expected in a typical blast. Figure 5 shows the graphic representation of data provided in Table 4.

Table 4: Distances required for maintaining specific vibration levels at specific charge masses.

No.	Charge Mass (kg)	Distance (m) 10mm/s PPV Limit	Distance (m) 25mm/s PPV Limit	Distance (m) 75mm/s PPV Limit
1	200.0	250	143	74
2	400.0	353	203	104
3	600.0	433	248	128
4	800.0	500	287	147

5	1000.0	559	321	165
6	1200.0	612	351	181
7	1400.0	661	379	195
8	1600.0	707	406	208
9	1800.0	750	430	221
10	2000.0	790	454	233
11	2200.0	829	476	244
12	2400.0	866	497	255
13	2600.0	901	517	266
14	2800.0	935	537	276
15	3000.0	968	556	285
16	3200.0	1000	574	295
17	3400.0	1030	591	304
18	3600.0	1060	609	313
19	3800.0	1089	625	321
20	4000.0	1118	641	330

Figure 5: Distance versus charge mass for limiting vibration levels.



Secondly the required charge masses to yield different vibration levels (10mm/s, 25 mm/s and 75 mm/s) at various distances was calculated and presented in Table 5 below. This is used to consider what maximum charge mass can be allowed for specific distance of interest.

Table 5: Limiting charge masses at specific distances for maintaining specific ground vibration levels.

Distance (m)	Charge Mass (kg) 10mm/s PPV Limit	Charge Mass (kg) 25mm/s PPV Limit	Charge Mass (kg) 75mm/s PPV Limit
50.0	8	24	92
100.0	32	97	368
150.0	72	219	828
200.0	128	389	1473
250.0	200	608	2301
300.0	288	875	3314
350.0	392	1191	4510
400.0	512	1556	5891
450.0	648	1969	7456
500.0	800	2430	9205
550.0	969	2941	11138
600.0	1153	3500	13255
650.0	1353	4107	15556
700.0	1569	4764	18042
750.0	1801	5469	20711
800.0	2049	6222	23565
850.0	2313	7024	26602
900.0	2593	7875	29824
950.0	2890	8774	33230
1000.0	3202	9722	36820

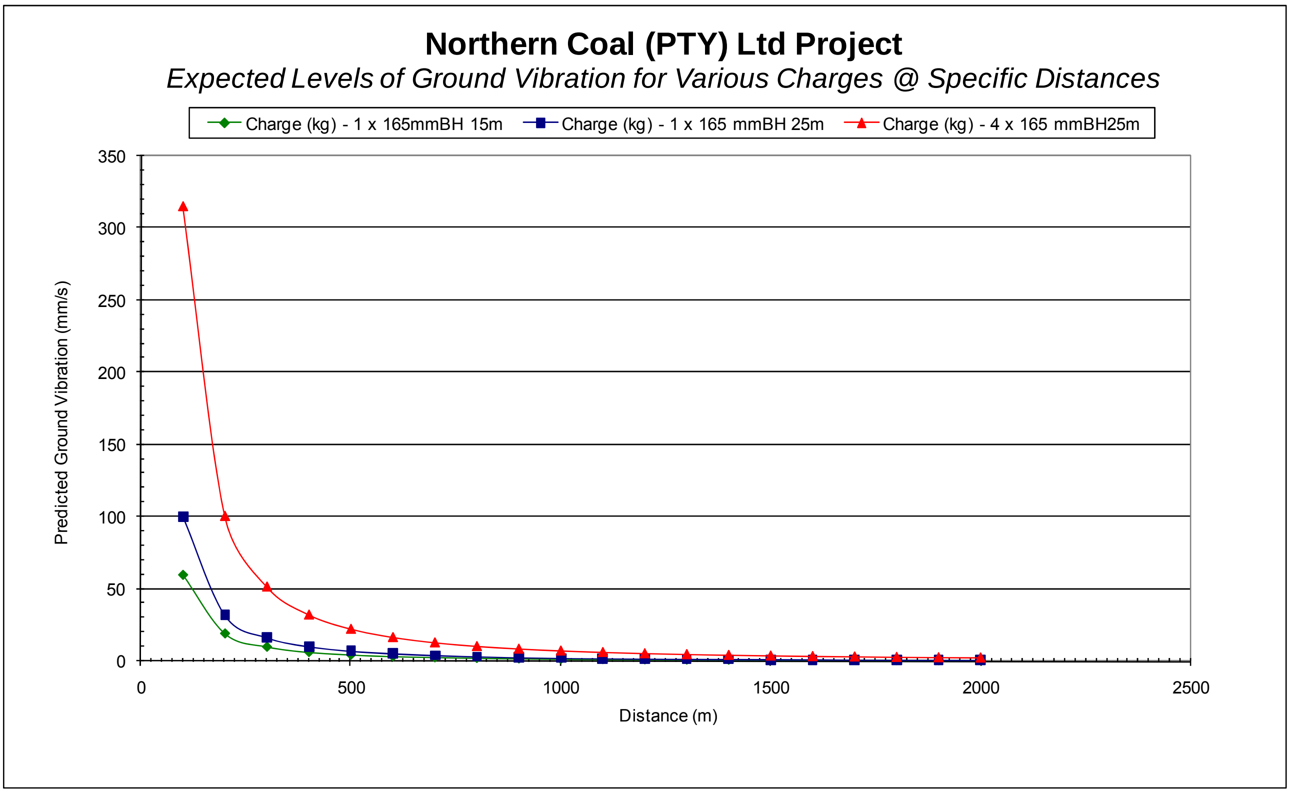
Based on the design presented on expected drilling and charging design, the following Table 6 shows expected ground vibration levels (PPV) for various distances calculated at three different charge masses. A low charge mass, the expected maximum charge mass per delay and a maximum charge mass as worst case scenario.

Table 6: Expected ground vibration at various distances from charges applied in this study.

Distance (m)	Expected PPV (mm/s) for Charge (kg) - 1 x 165mm BH 15m	Expected PPV (mm/s) for Charge (kg) - 1 x 165mm BH 25m	Expected PPV (mm/s) for Charge (kg) - 4 x 165mm BH25m
50.0	59.8	100.7	315.7
100.0	19.1	32.1	100.6
150.0	9.8	16.4	51.5
200.0	6.1	10.2	32.0
250.0	4.2	7.1	22.2
300.0	3.1	5.2	16.4
350.0	2.4	4.1	12.7
400.0	1.9	3.3	10.2
450.0	1.6	2.7	8.4
500.0	1.3	2.3	7.1
550.0	1.1	1.9	6.0
600.0	1.0	1.7	5.2
650.0	0.9	1.5	4.6
700.0	0.8	1.3	4.1
750.0	0.7	1.2	3.6
800.0	0.6	1.0	3.3
850.0	0.6	0.9	2.9
900.0	0.5	0.9	2.7
950.0	0.5	0.8	2.5
1000.0	0.4	0.7	2.3

Figure 7 below shows the relationship of ground vibration over distance for the three charges considered as given in table 6 above. The attenuation of ground vibration over distance is clearly seen from the graph. Ground vibration attenuation follows a logarithmic trend and the graph indicates this trend. The graph can be used to scale expected ground vibration at specific distances for the same maximum charges as used in this report. The expected vibration level at specific distance can be read from the graph, provided the same maximum charges are applicable, or by rough estimate if the charge per delay should be between the charge masses applied for this case.

Figure 7: Ground vibration over distance for maximum charge mass.



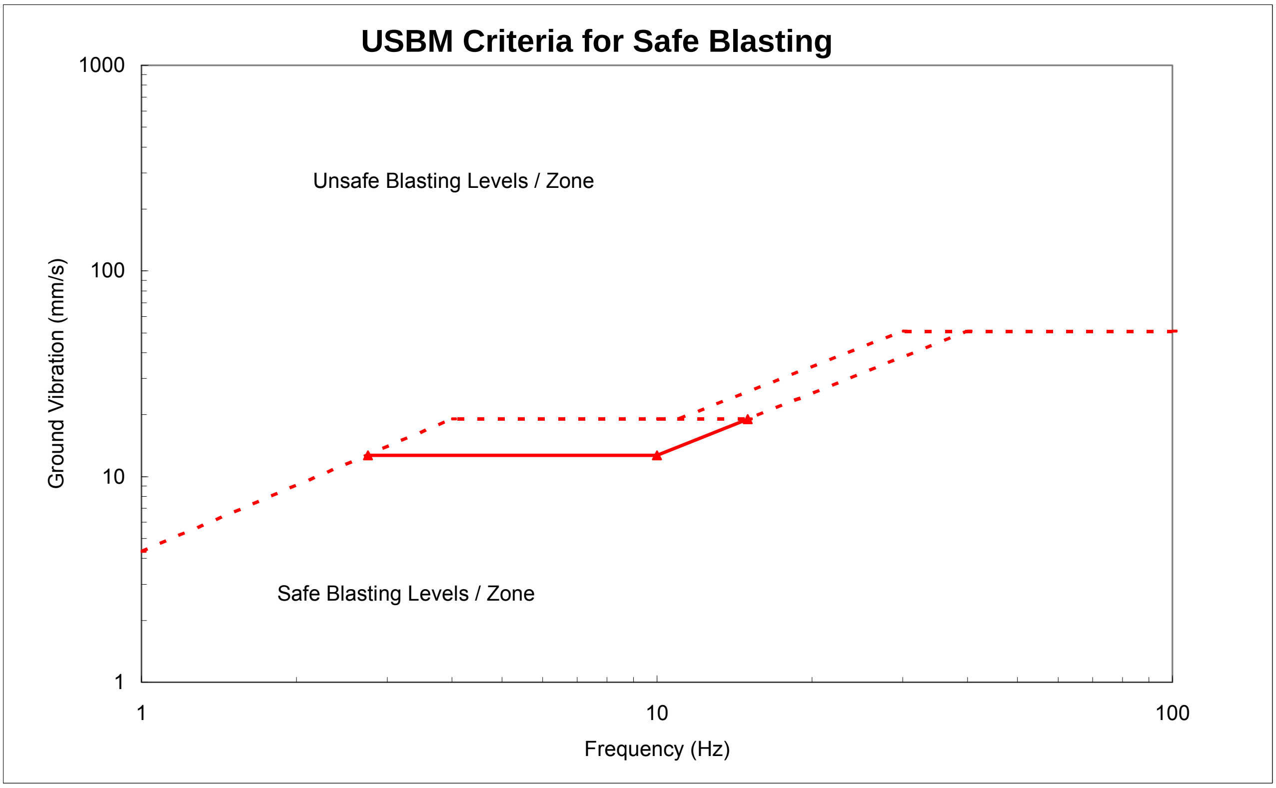
6.2 Limitations on Structures

Limitations on ground vibration are in the form of maximum allowable levels for different installations and structures. These levels are normally quoted in millimetres per second i.e. velocity of the particles.

There are fixed South African criteria for safe ground vibration levels. Early day recommendations were as follows: 25 mm/s maximum at private structures if frequency of ground vibration is greater than 10 Hz and 12.5 mm/s where frequency of ground vibration is less than 10 Hz.

Currently the United States Bureau of Mines (USBM) criterion for safe blasting is applied where private structures are of concern. This is a process of evaluating the vibration amplitudes and frequency of the vibrations according to set rules for preventing damage. The vibration amplitudes and frequency is then plotted on a graph. The graph indicates two main areas, 1. The safe blasting criteria area and 2. The Unsafe blasting criteria area. When ground vibration is recorded and the amplitude in mm/s is analysed for frequency it plots this relationship on the USBM graph. If data falls in the lower part of the graph then the blast was done safely. If the data falls in the upper part of the graph then the probability of inducing damage to mortar and brick structures increases significantly. There is a relationship between amplitude and frequency due to the natural frequencies of structures. This is normally low – below 10 Hz – and thus the lower the frequency, the lower the allowable amplitude. Higher frequencies allows for higher amplitudes. The extra lines on the graph are more detailed for specific type walls and structure configurations. Locally we are only concerned with the lowest line on the graph. This is a pre blast analysis but predictions help us determine expected amplitudes and experience has taught us what frequencies could be expected. The USBM graph for safe blasting was developed by the United States Bureau of Mines through research and data accumulated from sources other than their own research. Figure 8 shows an example of a USBM analysis graph.

Figure 8: USBM Analysis Graph.



Additional limitations that should be considered are as follows. These were determined through research and various institutions:

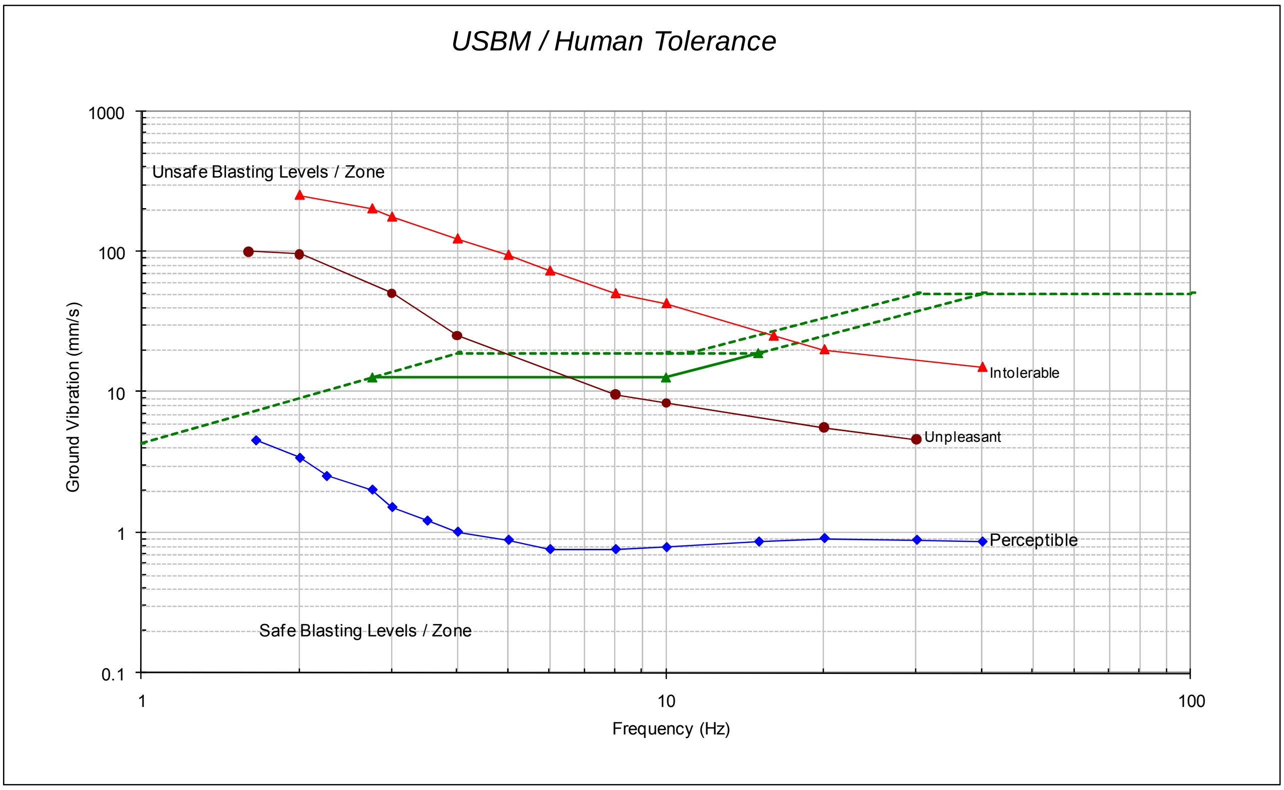
National Roads/Tar Roads: 150 mm/s
Steel pipelines: 50 mm/s
Electrical Lines: 75 mm/s
Railway: ˜ 150 mm/s
Concrete aged less than 3 days: 5mm/s
Concrete after 10 days: 200 mm/s
Sensitive Plant equipment: 12 or 25 mm/s depending on type – some switches could trip at levels less than 25 mm/s.

Considering the above limitations BM&C work is based on the following:
a) USBM criteria for safe blasting,
b) The additional limitations provided,
c) Consideration of private structures and
c) Should these structures be in poor condition is the basic limit of 25 mm/s reduced to 12.5 mm/s.

6.3 Limitations with regards to Human perceptions

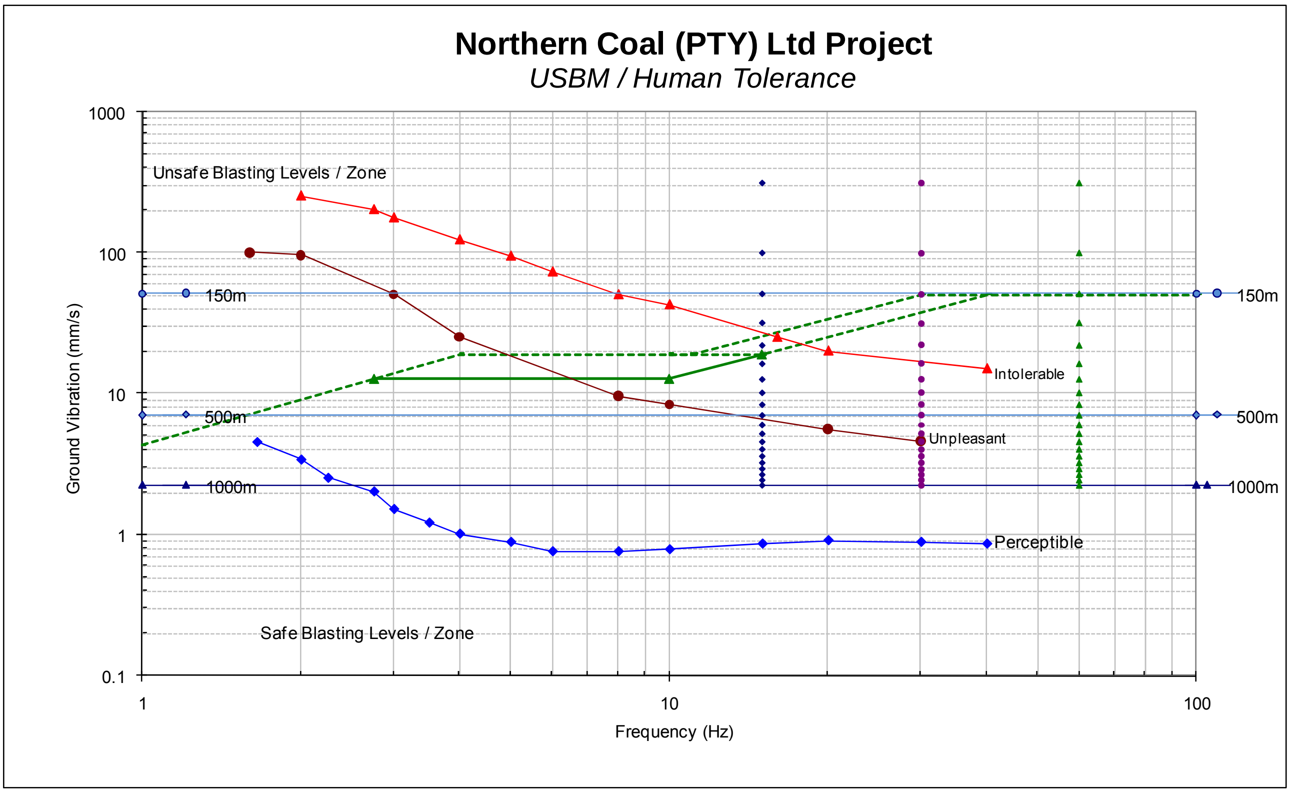
A further aspect of ground vibration and frequency of vibration is the Human perception. It should be realized that the legal limit for structures is significantly greater than the comfort zones for people. Humans and animals are sensitive to ground vibration and vibration of the structures. Research has shown that humans will respond to different levels of ground vibration and at different frequencies. Ground vibration is experienced as “Perceptible”, “Unpleasant” and “Intolerable” (only to name three of the five levels tested) at different vibration levels for different frequencies. This is indicative of the human’s perceptions on ground vibration and clearly indicates that humans are sensitive to ground vibration. This “tool” is only a guideline and helps with managing ground vibration and the respective complaints that people could have due to blast induced ground vibrations. Humans already perceive ground vibration levels of 4.5 mm/s as unpleasant.
Generally people also assume that any vibrations of the structure – windows or roofs rattling – will cause damage to the structure. Air blast also induces vibration of the structure and is the cause of nine out of ten complaints. (See Figure 9)

Figure 9: USBM Analysis with human perception,



Considering the effect of ground vibration with regards to human perception, vibration levels calculated were applied to various frequencies and plotted with expected human perceptions on the USBM safe blasting criteria graph (See Figure 10 below). On the graph are indicators of the effect of vibration amplitude at various distances for three specific frequencies 15, 30 and 60 Hz. The frequency range selected is the expected range for frequencies that will be measured for ground vibration. The graph also shows the relationship of ground vibration and the USBM analysis / criteria for safe blasting. Considering the maximum charge per delay of 2102kg there is indication that though levels of ground vibration are well within the safe blasting criteria at 1000m it will be strongly perceptible by people. At 500m the people’s perception would have changed from perceptible to unpleasant whilst the levels of ground vibration are still within the safe blasting zone. Ground vibration expected is still below the 10 mm/s level. Damage to structures (normal brick and

mortar) is still not induced. Even at some intolerable levels for humans at the higher frequencies the amplitude of ground vibration is still within the safe blasting zone with regards to structures. People experience ground vibration more severely than what would be required to induce damage to structures. Figure 10 below shows this effect of ground vibration with regards to human perception.
Figure 10: The effect of ground vibration with regards to human perception plotted with the USBM criteria for safe blasting. Highest charge mass applied.



7. Air blast and Prediction

Air blast or air-overpressure is pressure acting and should not be confused with sound that is within audible range (detected by the human ear). Sound is also a build up from pressure but is at a completely different frequency to air blast. Air blast is normally associated with frequency levels less than 20 Hz, which is the threshold for hearing. Air blast is the direct result from the blast process although influenced by meteorological conditions the final blast layout, timing, stemming, accessories used, covered or not covered etc. all has an influence on the outcome of the result.

The three main causes of air blasts can be observed as:

1. Direct rock displacement at the blast; the air pressure pulse (APP),
2. Vibrating ground some distance away from the blast; rock pressure pulse (RPP),
3. Venting of blast holes or blowouts; the gas release pulse (GRP).

7.1 Limitations with regards to Air blast

The recommended limit for air blast currently applied in South Africa is 134 dB. This is specifically pertaining to air blast or otherwise known as air-overpressure. This takes into consideration where public is of concern. Air-overpressure is pressure acting and should not be confused with sound that is within audible range (detected by the human ear). However, all attempts should be made to keep air blast levels generated from blasting operations below 120 dB or greater magnitude toward critical areas where public is of concern, as this will ensure that the minimum amount of disturbance is generated towards the critical areas surrounding the mining area.

Based on work carried out by Siskind *et.al.* (1980)[1], 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)[2] have published the following estimates of damage thresholds based on empirical data (Table 7).

Table 7: Damage limits for air blast.

Level	Description
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

Levels given in Table 6 are at the point of measurement.

7.2 Air blast Prediction

An aspect that is not normally considered as pre-operation definable is the effect of air blast. This is mainly due to the factor that air blast is an aspect that can be controlled to a great degree by applying basic rules. Air blast is the direct result from the blast process, although influenced by meteorological conditions, the final blast layout, timing, stemming, accessories used, covered or not covered etc. all has an influence on the outcome of the result. Standards do exist and predictions can be made, but it must be taken in to account that predictions of air blast is most effective only when used in conjunction with charges on surface and normally referred to detonation of TNT as a reference. Blasts that are normally covered show the least effect on air blast. However even covered blasts with the use of detonating cord can yield high air blast levels when pieces of the detonation cord that is used for indicators are not covered. Covered blasting is normally used in blasting of trenches etc. in close proximity of structures.

The following equation is associated with predictions of air blast, but is considered by the author as subjective. The only real fact is that air blast does decrease over distance and nominally at a rate of -6dB for each doubling of the distance from the source. However applying equation 2 gives some indication of expected levels of air blast and the attenuation over distance.

Equation 2:
$L = 165 - 24 \, Log_{10} (D / E^{1/3})$
Where:
L = Air blast level (dB)
D = Distance from source (m)
E = Maximum charge mass per delay (kg)

All though the above equation was applied for prediction of air blast levels, additional measures are also recommended in order to ensure that air blast and associated fly-rock possibilities are minimized completely.

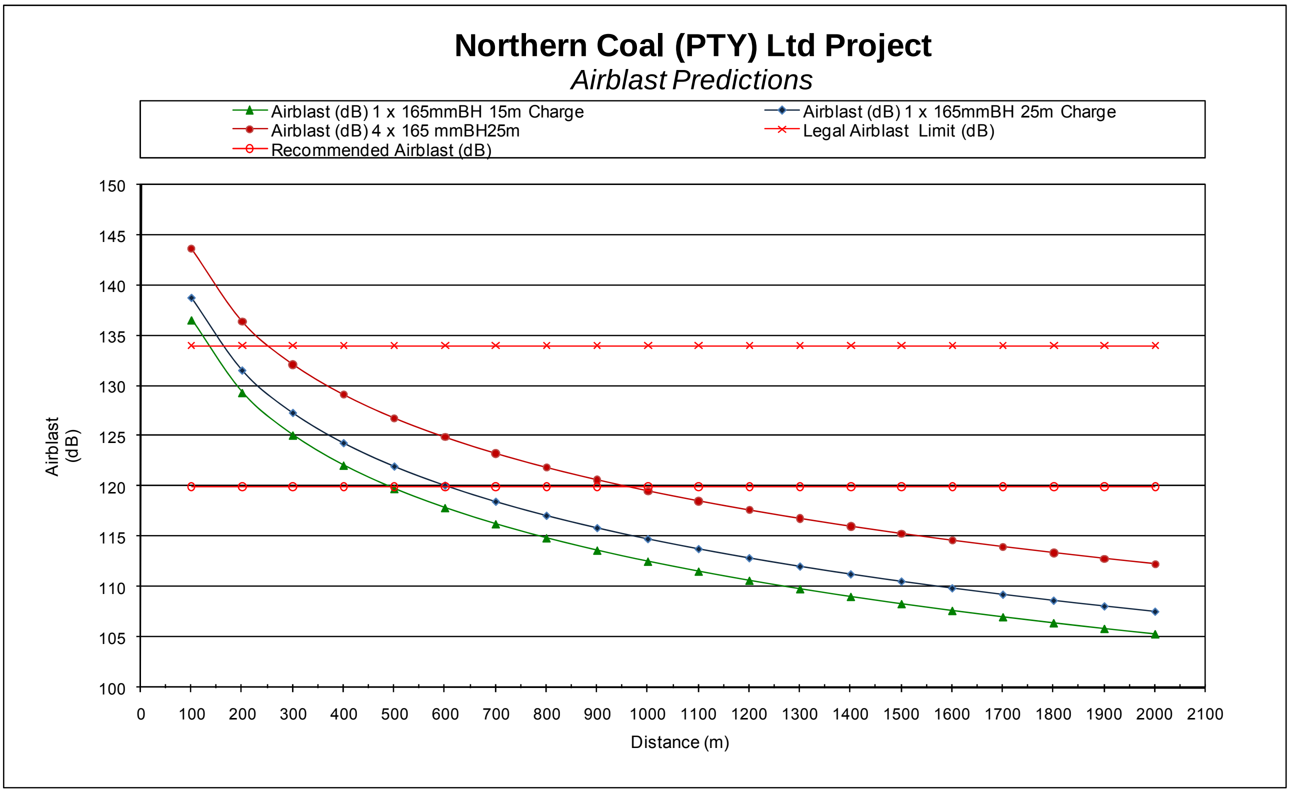
As discussed earlier the prediction of air blast is very subjective. Following in Table 8 below is a summary of values predicted according to equation 2.

Table 8: Air blast predicted values.

Distance (m)	Airblast (dB) 1 x 165mmBH 15m Charge	Airblast (dB) 1 x 165mmBH 25m Charge	Airblast (dB) 4 x 165 mmBH25m
100.0	137	139	144
200.0	129	132	136
300.0	125	127	132
400.0	122	124	129
500.0	120	122	127
600.0	118	120	125
700.0	116	118	123
800.0	115	117	122
900.0	114	116	121
1000.0	113	115	120
1100.0	112	114	119
1200.0	111	113	118
1300.0	110	112	117
1400.0	109	111	116
1500.0	108	111	115
1600.0	108	110	115
1700.0	107	109	114
1800.0	106	109	113
1900.0	106	108	113
2000.0	105	108	112

Figure 11 below shows the predicted values for air blast as given in Table 7 with values for air blast predicted with cover.

Figure 11: Predicted air blast.



8. Fly Rock

Fly rock is caused by unconfined detonation of explosives, i.e. improper stemming / tamping used or under burdened blast holes etc. It is possible to blast without any fly rock with proper confinement of the explosive charges within blast holes using proper stemming procedures and materials. Proper control of stemming will prevent any fly rock or excessive airblast and noise being generated from the blast surfaces. Stemming is further required to ensure that explosive energy is efficiently used to its maximum. Free blasting with no control on stemming cannot be allowed as this will result in poor blast results and possible damage to any nearby structures.

There are more intensive predictions for fly-rock but generally the best value of predicting fly-rock is to charge in such a way that the possibilities of fly-rock is minimized to the absolute minimum according to the following: Stemming length a minimum of 30 hole diameters and stemming material size must be in the order of 10% of the hole diameter.

9. Noxious Fumes

Explosives currently used are required to be oxygen balanced. Oxygen balance refers to the stoichiometry of the chemical reaction and the nature of gases produced from the detonation of the explosives. The creation of poisonous fumes such as nitrous oxides and carbon monoxide are particular undesirable. Factors contributing to undesirable fumes are typically: poor quality control on explosive manufacture, damage to explosive, lack of confinement, insufficient charge diameter, excessive sleep time, and specific types of ground can also contribute to fumes.

10. Legal requirements

Any further legal requirements as required by i.e. Mine Health and Safety Act, or the Department of Minerals and Energy Affairs (DME) due to the close proximity of the structures in question**.**

Consideration must then also be given to any further legal aspects that may be imposed by the DME following the outcome of review of this document and its recommendations.

11. Discussion of Possible Effects due to Blasting Operations

11.1 Ground vibration and Human Perception

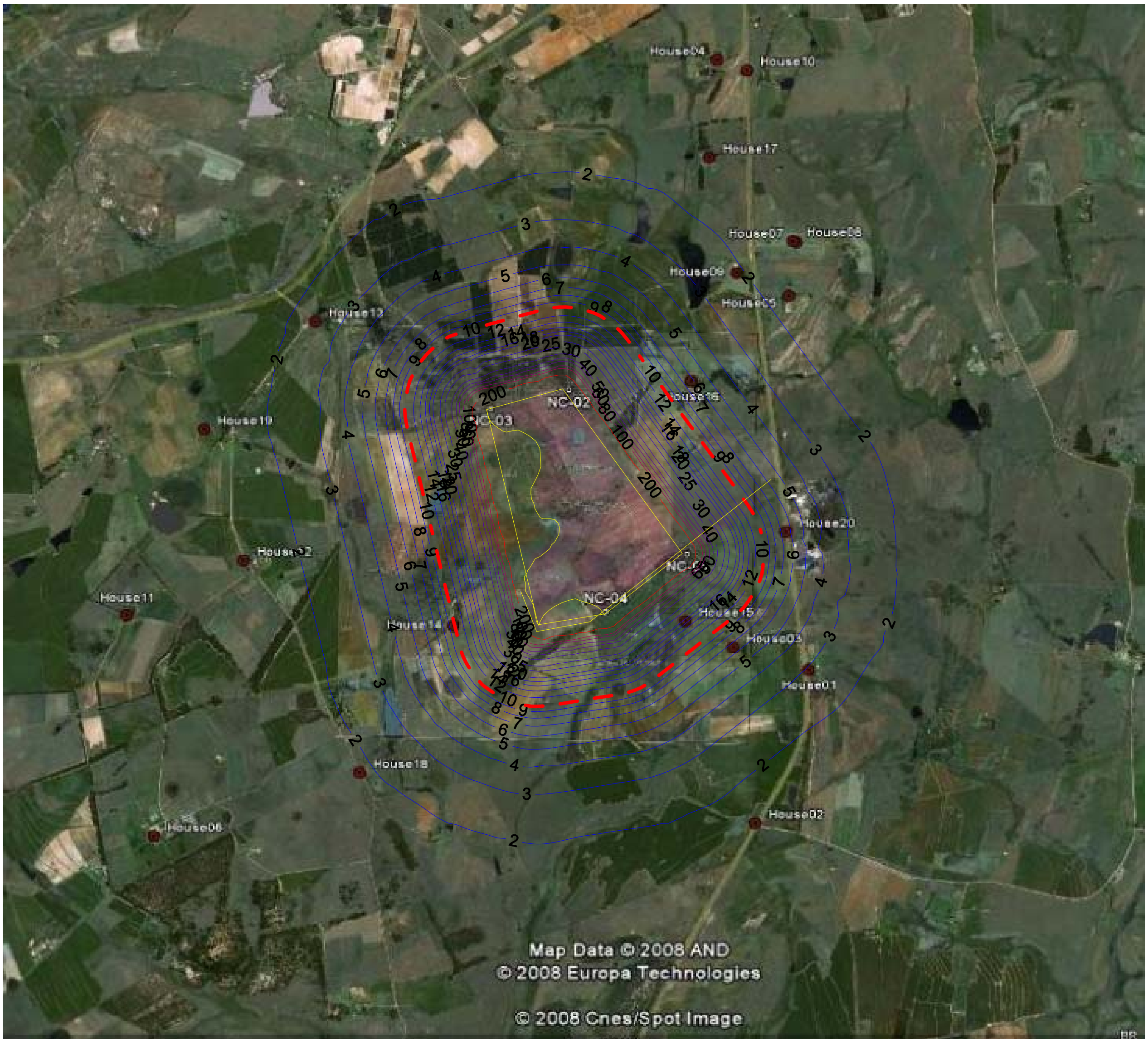
Review of the area surrounding the Weltevreden 381JT Portions 15 and 16 Project showed various structures and farms that were identified and taken into consideration. Expected ground vibration levels were calculated for each of these structure locations surrounding the mining area. Ground vibration was calculated from the boundary of the mining area. This was done as no detail of any blocks or areas to be blasted is yet available. This means that vibration is taken from the edge as if it will be the closest place were drilling and blasting will be done to the various structures.
Firstly a worst case scenario was calculated and simulated. In this case 4 x the expected charge mass for a 165 mm diameter blasthole was used at 25 m blasthole depths. The outcome of the simulation is presented in Figure 12 below. Figure 13 shows the zoomed area of influence. Indicated on figures 12 & 13 is structures/installations identified that could be influenced. Ground vibration predictions were done considering 2600m radius around the opencast mining area. Table 9 below shows a summary of the nearest different structures with specific distances, expected ground vibration and possible concerns.

Table 9: Expected ground vibration levels for the various structures.

No.	Structure	Direction from Pit Position	Shortest Distance (m)	Max Charge	Predicted PPV (mm/s)	Possible Concern
1	House01	SE	1676	2102	3.0	None but Perceptible
2	House02	SE	2595	2102	1.5	None but Perceptible
3	House03	SE	1021	2102	6.8	None but Uncomfortable
4	House04	NE	3667	2102	0.8	None
5	House05	NE	2303	2102	1.8	None but Perceptible
6	House06	SW	4342	2102	0.6	None
7	House07	NE	2681	2102	1.4	None but Perceptible
8	House08	NE	2681	2102	1.4	None but Perceptible
9	House09	NE	2016	2102	2.2	None but Perceptible
10	House10	NE	3708	2102	0.8	None
11	House11	SW	3890	2102	0.8	None
12	House12	W	2656	2102	1.4	None but Perceptible
13	House13	NW	1904	2102	2.4	None but Perceptible
14	House14	SE	810	2102	10.0	None but Perceptible
15	House15	SW	534	2102	19.9	None but Intolerable
16	House16	NE	1028	2102	6.8	None but Uncomfortable
17	House17	NE	2746	2102	1.3	None but Perceptible
18	House18	SW	2344	2102	1.7	None but Perceptible
19	House19	W	2786	2102	1.3	None but Perceptible
20	House20	E	989	2102	7.2	None but Uncomfortable

(Intentionally Left Open)

Figure 12: Ground vibration influence from maximum charge.



Note: Red dotted line is the 10mm/s level.

(Intentionally Left Open)

Figure 13: Zoomed area around mining area.

Note: Red dotted line is the 10mm/s level.

Review of structures and installations surrounding the mining area structures locations indicated as House 14 and 15 falls within or on the 10mm/s indicator line. The 10 mm/s is still within accepted limits but the human perception could be problematic. Expected level house 15 is in the order of 20 mm/s. This will have implication that planning, design, prepare and monitoring of blasts must be done when blasting is done in the area closest to this house. The rest of the structures listed do not show any damage concerns.

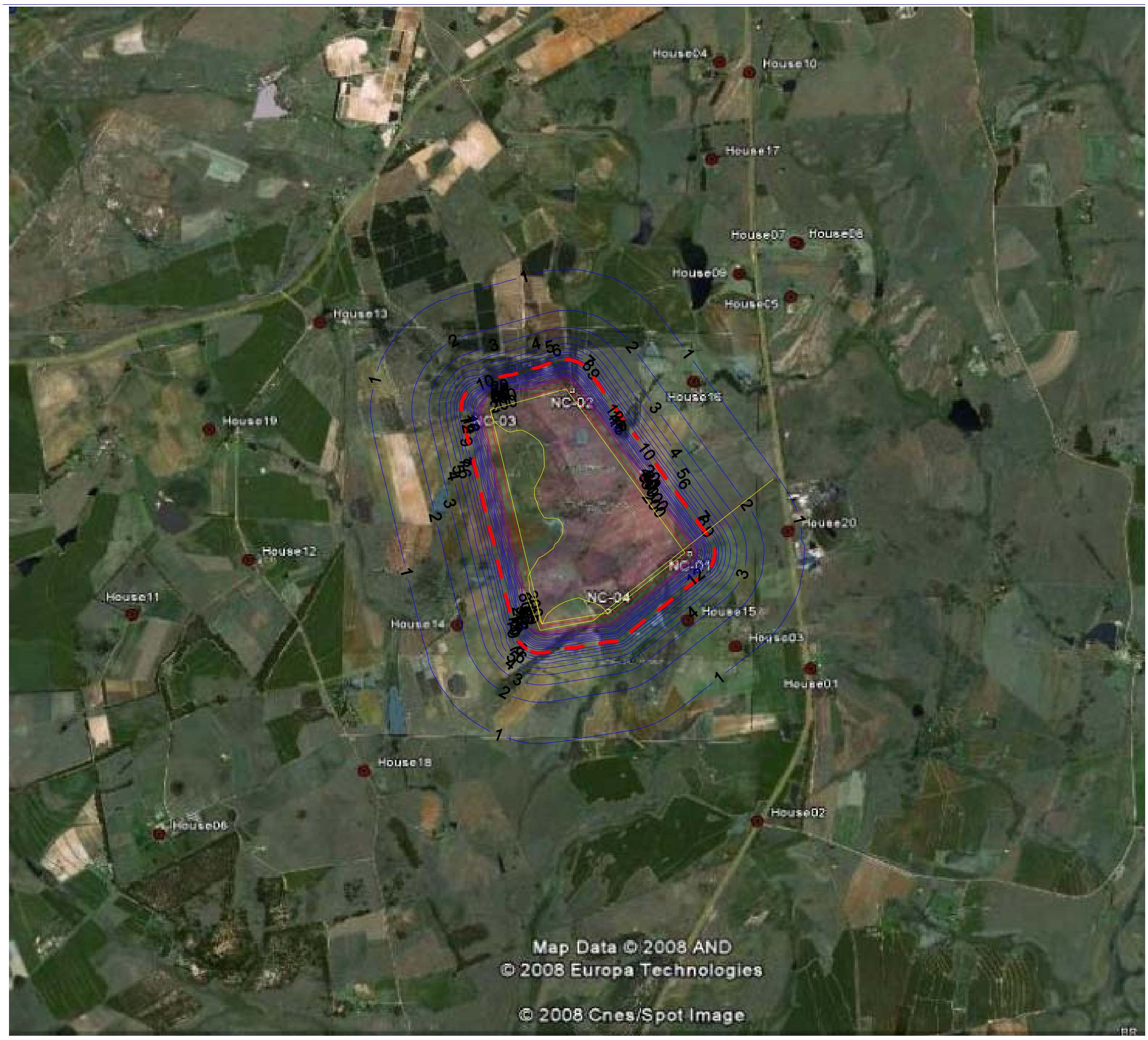
Reconsidering of the outcome of the initial modelling a smaller charge mass was modelled. Considering the smaller charge presented in the ground vibration predictions of 280 kg from 165 mm diameter blasthole, single charge, the same ground vibration prediction was done and level contours drawn. Figure 14 below shows the outcome of the modelling for the same area. Table 10 shows expected levels of ground for the various structures at smaller charge modelled.

Table 10: Expected ground vibration levels for the various structures at reduced charge mass.

No.	Structure	Direction from Pit Position	Shortest Distance (m)	Max Charge	Predicted PPV (mm/s)	Possible Concern
1	House01	SE	1676	280	0.6	None
2	House02	SE	2595	280	0.3	None
3	House03	SE	1021	280	1.3	None but Perceptible
4	House04	NE	3667	280	0.2	None
5	House05	NE	2303	280	0.3	None
6	House06	SW	4342	280	0.1	None
7	House07	NE	2681	280	0.3	None
8	House08	NE	2681	280	0.3	None
9	House09	NE	2016	280	0.4	None
10	House10	NE	3708	280	0.2	None
11	House11	SW	3890	280	0.1	None
12	House12	W	2656	280	0.3	None
13	House13	NW	1904	280	0.5	None
14	House14	SE	810	280	1.9	None but Perceptible
15	House15	SW	534	280	3.8	None but Perceptible
16	House16	NE	1028	280	1.3	None but Perceptible
17	House17	NE	2746	280	0.3	None
18	House18	SW	2344	280	0.3	None
19	House19	W	2786	280	0.2	None
20	House20	E	989	280	1.4	None but Perceptible

(Intentionally Left Open)

Figure 14: Mining operation with smallest charge mass modelled.



Note: Red dotted line is the 10mm/s level.

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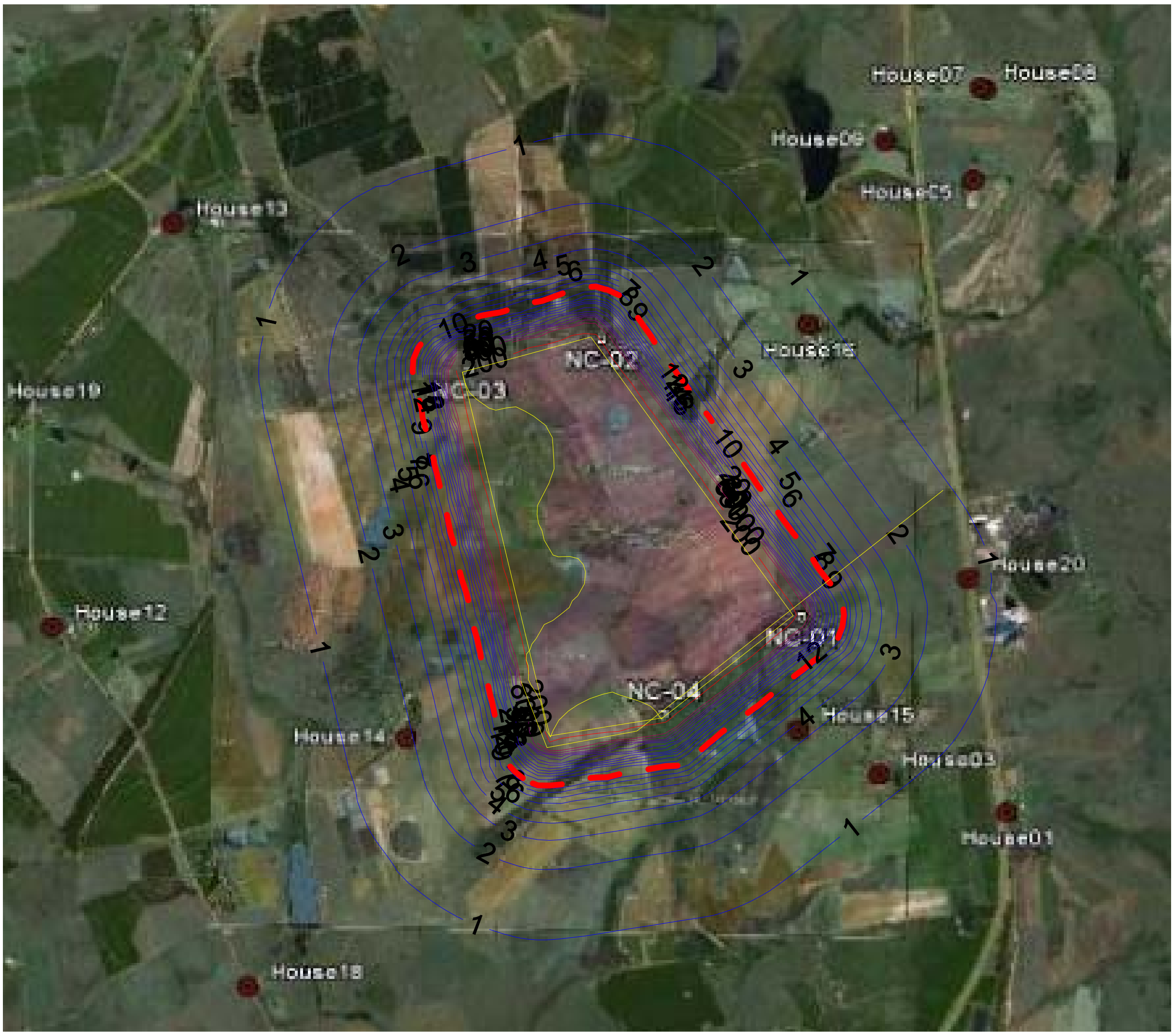
Figure 15: Zoomed area of mine operation with smallest charge mass modelled.



Note: Red dotted line is the 10mm/s level.

Modelling of the lower charge mass per delay clearly indicates a significant reduction of ground vibration levels. Simulations show that blasting operations in the proposed mining area will be possible with specific changes to charge mass per delay. Consideration can be given to even lower charge masses, but design will be required to consider the costing and effective mining implications as well. The reduction of charge mass per delay will certainly assist in mitigating the effect of ground vibration.

11.2 Air blast

The effect of air blast, if not controlled properly, is in my opinion a factor that could be problematic. Maybe not in the sense of damage being induced but rather having an impact – even at low levels of roofs and windows that could result in complaints from people. In more than one case this effect is misunderstood and people consider this effect as being ground vibration and damaging to their house structures. Review of expected data for the three charges evaluated is given in table 11 below. Table 11 shows that 4 x blastholes of 165 mm diameter levels are on just greater than the legal limit between 200m and 300m distance. The minimum distance to maintain levels of 134 dB is then in the order of 250m for the largest possible charge mass. This distance is significantly less than the distance between the mining operation and the nearest house at 534m. Predictions for the specific structures / installations identified are presented in table 12 below. Figure 13 below shows the modelling of expected levels of airblast around the mining area. Levels predicted do indicate that levels will be below any level of possible structural damage. However it will be recommended that levels be maintained at maximum levels of 120 dB. This will minimise the effect on structures and subsequent peoples experience when blasting is done. Considering the information in table 12 it can be seen that five structures are showing perceptible levels of airblast. As said these levels are below damage criteria but could have influence such as rattling of windows and large roof surfaces. House 14 has nursery tunnels that will need consideration. Level of 120 dB is not yet high enough than to induce damage but could be problematic when the plastic is at life end. The typical plastic used will withstand significant stresses but is also influenced by the sun and age significantly. It is uncertain what plastic is used for these tunnels and therefore not possible to determine that tensile strengths applicable. In normal cases the influence of wind is more significant than that of airblast due to the short durations.

Table 11: Expected air blast levels.

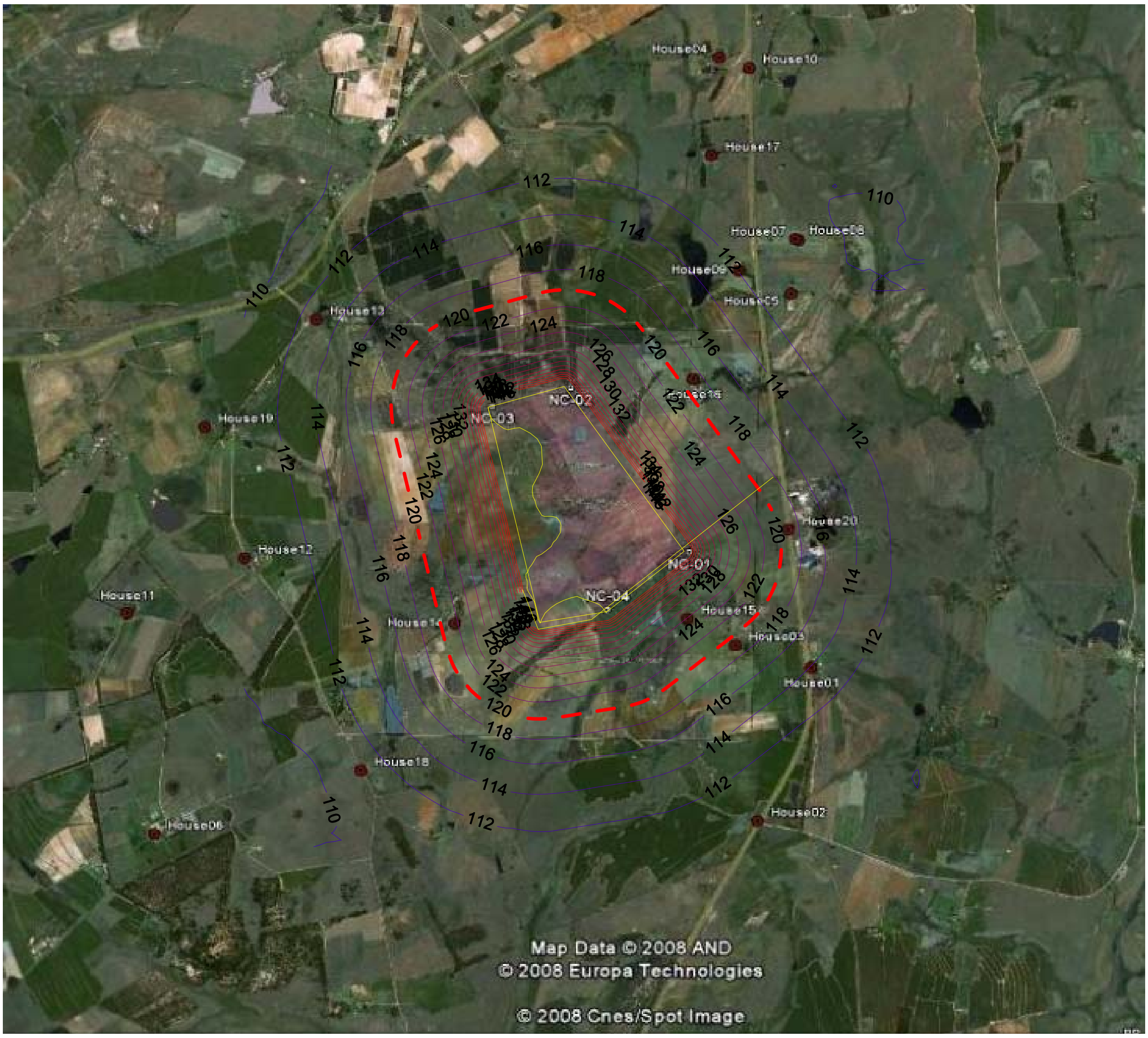
Distance (m)	Airblast (dB) 1 x 165mmBH 15m Charge	Airblast (dB) 1 x 165mmBH 25m Charge	Airblast (dB) 4 x 165mmBH 25m Charge
100.0	137	139	144
200.0	129	132	136
300.0	125	127	132
400.0	122	124	129
500.0	120	122	127
600.0	118	120	125
700.0	116	118	123
800.0	115	117	122
900.0	114	116	121
1000.0	113	115	120
1100.0	112	114	119
1200.0	111	113	118
1300.0	110	112	117
1400.0	109	111	116
1500.0	108	111	115
1600.0	108	110	115
1700.0	107	109	114
1800.0	106	109	113
1900.0	106	108	113
2000.0	105	108	112

Table 12: Expected levels of airblast at the identified structures.

No.	Structure	Direction from Pit Position	Shortest Distance (m)	Max Charge	Airblast (dB)	Possible Concern
1	House01	SE	1676	2102	114	None
2	House02	SE	2595	2102	110	None
3	House03	SE	1021	2102	119	Perceptible
4	House04	NE	3667	2102	106	None
5	House05	NE	2303	2102	111	None
6	House06	SW	4342	2102	104	None
7	House07	NE	2681	2102	109	None
8	House08	NE	2681	2102	109	None
9	House09	NE	2016	2102	112	None
10	House10	NE	3708	2102	106	None
11	House11	SW	3890	2102	105	None
12	House12	W	2656	2102	109	None
13	House13	NW	1904	2102	113	None

14	House14	SE	810	2102	122	Perceptible
15	House15	SW	534	2102	126	Perceptible
16	House16	NE	1028	2102	119	Perceptible
17	House17	NE	2746	2102	109	None
18	House18	SW	2344	2102	111	None
19	House19	W	2786	2102	109	None
20	House20	E	989	2102	120	Perceptible

Figure 13: Simulation of airblast levels for the areas of concern using maximum charge.



Note: Red dotted line is the 120 dB level.

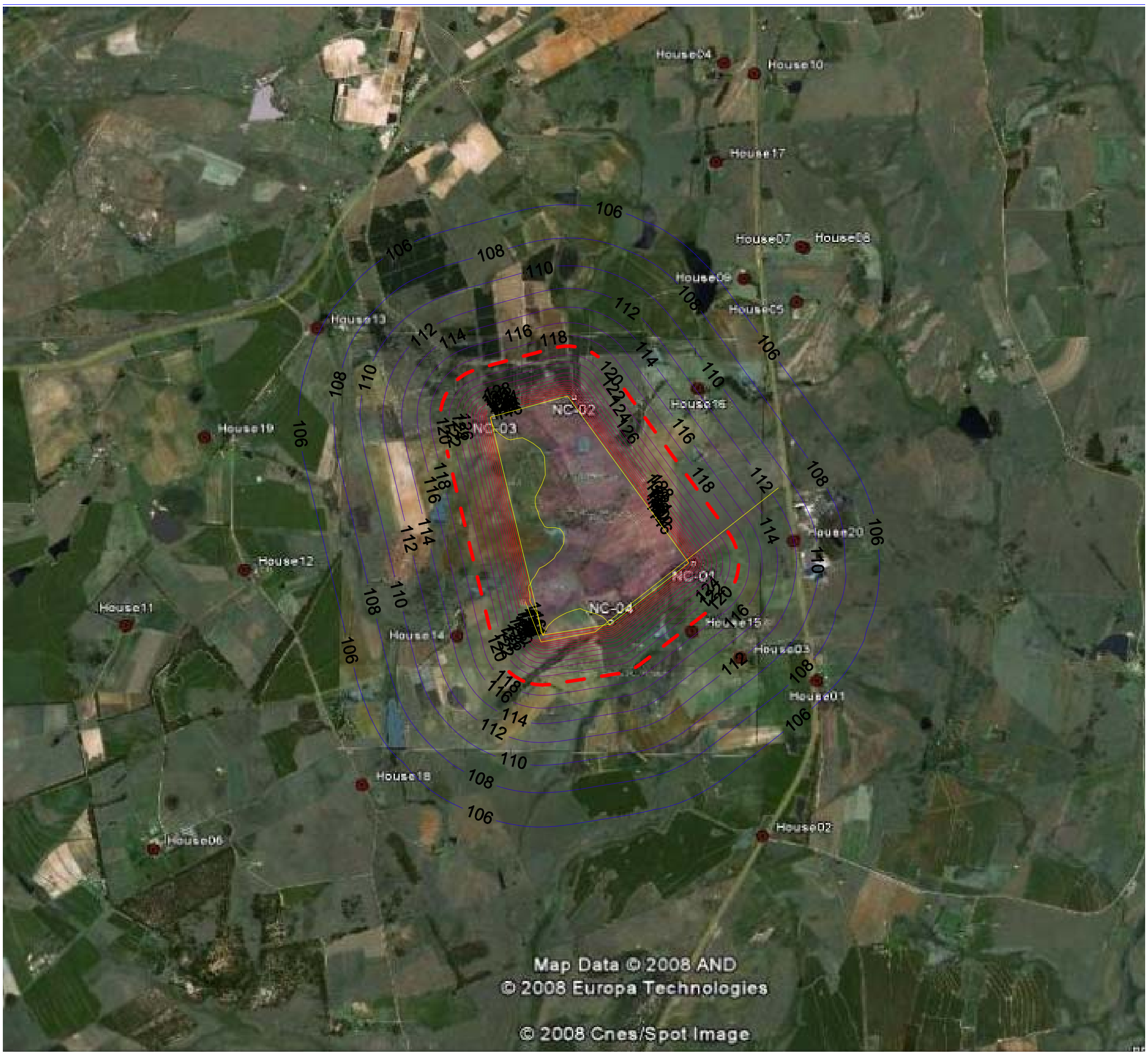
Air blast normally generates rattling of roofs and windows which could be easily misjudged by house owners as ground vibration. These levels do not need to be excessively high in order to upset the owners. Levels of air blast required to induce damage are in the order of 145 dB and greater. In some areas the levels could be perceptible but possible damage to the nearest structures is low and is not expected to be problematic. However considering the human perception the airblast was remodelled using the smallest charge mass per delay and is presented here. Table 13 shows the expected levels for the identified structures with the smallest charge considered. Review of results shows decrease from 126 dB to 119dB for house 15. 119dB could still be perceptible but is well below of any damage to structures. Figure 14 shows the simulation for the smallest charge used in calculations. This is a significant reduction and has possibility of less influence with regards to human perceptions.

Table 13: Expected airblast levels from the smallest charge designed.

No.	Structure	Direction from Pit Position	Shortest Distance (m)	Max Charge	Airblast (dB)	Possible Concern
1	House01	SE	1676	2102	107.2	None
2	House02	SE	2595	2102	102.6	None
3	House03	SE	1021	2102	112.4	None
4	House04	NE	3667	2102	99.0	None
5	House05	NE	2303	2102	103.9	None
6	House06	SW	4342	2102	97.3	None
7	House07	NE	2681	2102	102.3	None
8	House08	NE	2681	2102	102.3	None
9	House09	NE	2016	2102	105.3	None
10	House10	NE	3708	2102	98.9	None
11	House11	SW	3890	2102	98.4	None
12	House12	W	2656	2102	102.4	None
13	House13	NW	1904	2102	105.9	None
14	House14	SE	810	2102	114.8	None
15	House15	SW	534	2102	119.1	Perceptible
16	House16	NE	1028	2102	112.3	None
17	House17	NE	2746	2102	102.0	None
18	House18	SW	2344	2102	103.7	None
19	House19	W	2786	2102	101.9	None
20	House20	E	989	2102	112.7	None

(Intentionally Left Open)

Figure 14: Simulation of airblast levels for the areas of concern using minimum charge.



Note: Red dotted line is the 120 dB level.

11.3 Fly-Rock

The possibility of fly-rock is probable. Poor control on stemming lengths and material will certainly result in fly rock. Sufficient control will be required for minimising the effect of fly rock. However this does not exclude the possibility of blasting. Most of the critical surface structures are located at distances further than 500m. Not saying the fly rock will not reach 500m, but 500m is generally accepted as a safe distance. Safe distance is determined by the blaster and not a rigid value. As said that the most important control on fly rock is the correct stemming length with the correct stemming material used. Proper blast preparation is of utmost importance and will include the correct drilling requirements i.e. burden and spacing. Considering stemming lengths a minimum of 30 blast hole diameters in length with a stemming aggregate of 10% blast hole diameter will be sufficient to control fly rock effectively.

11.4 Noxious Fumes

Dust and Noxious fumes should be controlled as best as possible. Fumes are generated by all explosives. Emulsion explosives that have been standing for a while and where water or certain geology factors are present could be generating fumes when blasting is done. Consideration should also be given to prevailing wind direction when blasting is done.

Typical controls that can be used are:
1.1.1 Proper stemming and stemming material
1.1.2 Blasts can be delayed when prevailing wind is blowing towards the area of concern
1.1.3 Do not leave blasts standing for long periods of time

11.5 Blast Initiation

The mining area is rather large and the influence will vary from actual position of the blast to be done. Considering the location of each blast, specifically close to the mining boundaries, blast design should be considered. Careful design of blasts and layout will ensure effective initiation and detonation. The use of effective timing and the proper downhole accessories, according to accepted standard practices must be considered. The use of the proper size primer according to blast hole diameter and depth must be applied. Proper surface timing in order to provide proper movement and relief must be designed. Incorrect initiation of a blast will lead to poor blast results i.e. poor fragmentation, blow outs, fly rock etc. Increased distance between receptors and the blasts will see reduced levels of ground vibration and airblast. These distances must be considered when decision is made between multiple blasthole detonation or single hole firing.

11.6 Safe Blasting Procedures

Standard safety procedures associated with blasting operations should be applicable. Each bench that will be drilled and blasted will require standard rules and regulations with regards to all safety aspects of drilling and blasting.
Some aspects that should be considered as well:

11.6.1 Placement of guards will be required to ensure that there are no people or animals within the safe distance as determined by the blaster when blasting,
11.6.2 The closing of roads within a safe radius as determined by the blaster. Traffic stops could be considered where necessary,
11.6.3 Pre-Blast Meeting & Documentation - A pre-blast meeting should be conducted prior to each blast to ensure that all aspects of safety are covered. This meeting should facilitate the procedures and actions required by each party or person and its responsibilities. This will be mainly for lasting on the closest bench,
11.6.4 Time of blasting should not be more than once per day.

11.7 Monitoring

It is recommended that a process of monitoring the blasting operations must be applied for all blasting to be done in the mine operation. This process should be to ensure that levels are within limits at all times. Early monitoring will also give indications of what ground vibrations levels are recorded at what distances and help with being proactive on the levels observed. It is proposed that at least four seismographs be placed at the positions as indicated on the figure 15 below.

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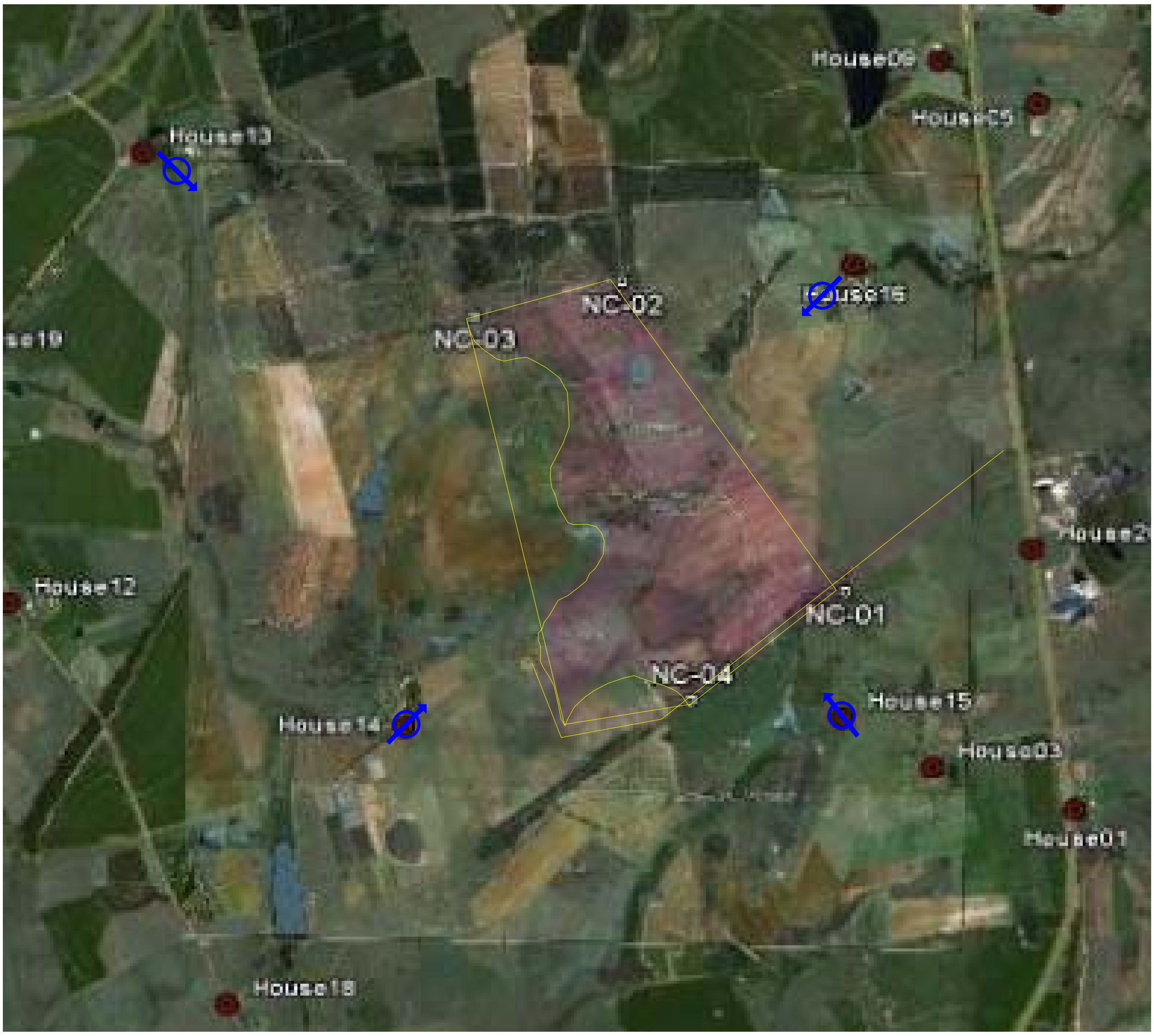
Figure 15: Proposed monitoring Positions.



ɸ Seismograph Position.

12. Additional Recommendations

Consideration should be given to the following recommendations.

12.1 Pre blast survey of all structures identified surrounding the mining area,
12.2 Ground vibration survey in the form of signature trace study to be done for determination of ground vibration constants that can be used for accurate prediction of ground vibration,
12.3 Design of blasts to ensure safe levels of ground vibration and airblast is maintained,
12.4 Redesign with alternative diameter blastholes and charge masses to accomplish safe blasting,
12.5 Investigate the possibility of electronic initiation,
12.6 Monitoring of blasting operations as per discussion.

13. Risk Assessments

Following is risk assessment of the various concerns covered by this report. The matrix below shows outcomes before any mitigation done and considers the worst case scenarios as basis.

1. Activity	Blasting	Blasting	Blasting	Blasting
2. Environmental Aspect	2.1 Ground Vibration			
		2.2 Air blast		
			2.3 Fly Rock	
				2.4 Fumes
3. Environmental Impacts				
• Receptors	People, Structures	People, Structures	People, Structures	People
• Resources	Blasting process	Blasting process	Blasting process	Blasting process
• Frequency Of Activity	Daily	Daily	Daily	Daily
• Frequency Of Impact	Daily	Daily	Daily	Daily
• Severity	Large	Large	Large	Large
• Spatial Scope	3km Radius	3km Radius	0.5km Radius	1km Radius
• Duration	LOM	LOM	LOM	LOM
Severity Of Impact Rating	3	3	2	4
Spatial Scope Of Impact Rating	3	3	2	2
Duration Of Impact Rating	4	4	4	4
Consequence	**10**	**10**	**8**	**10**
Frequency Of Activity / Duration Of Aspect Rating	4	4	4	4
Frequency Of Impact Rating	3	3	3	3
Likelihood	7	7	7	7
Risk Rating	**17**	**17**	**15**	**17**
Risk Level	High	High	High	High

Mitigation will be required for blasts done close to the mining border. The distance between blasts and the receptors will be the most influential. The greater the distance between receptors and the blast the less is the influence. Mitigation is specifically required with regards to ground vibration and airblast. Airblast is most probably the biggest concern as people will react to it and this could lead to complains. Fly rock will always require specific attention with regards to proper stemming lengths. Stemming length and proper stemming material is the appropriate method of controlling fly rock.

14. Knowledge Gaps

To the knowledge of the author there is no immediate concern with regards to shortfall in the information provided. More detailed mine plan may prove to be helpful for further mitigation of ground vibration and airblast. Considering the stage of the project, the data observed was sufficient to conduct an initial study. Surface surroundings change continuously and this should be taken into account prior to any final design and review of this report. This report is based on data provided and international accepted methods and methodology used for calculations and predictions.

15. Conclusion

The expected ground vibration and airblast levels from blasting operations required at the Northern Coal (PTY) Ltd Portion 15 and 16, farm Weltevreden 381JT project was calculated and considered in relation to the surrounding structures and installations. Some concerns were identified from review of the expected ground vibration and air blast levels. These concerns are however manageable and in no way such that blasting should be prohibited. The main concerns are related to distance between the mining area and the nearest structures – House 14 & 15 specific. Expected levels of ground vibration and airblast are within the allowed limits but levels are such that it could be perceptible. This in turn may lead to complains and subsequent investigations. Ground vibration levels at the closest houses are 10 and 19.9 mm/s respectively for the largest charge mass applied. Considering the reduced charge modelled, this will have a decreased ground vibration effect and reduce the risk significantly. This is within the general safety limit of 25 mm/s. All other structures / installations were well within limits with no significant effect. Mitigation in reducing the maximum charge mass per delay and design of blasts in the areas of house 14 & 15 will assist to control the ground vibration.

Airblast levels reviewed showed no direct concern with regards to damage to structures, but did indicate that mitigation of the ground vibration will also bring about reduced airblast levels. Maximum level observed was 126 dB at the nearest house. This is within accepted norm of 134dB. Reduced charges and control on stemming will be assisting in reducing the possibilities of complaints from home owners.

This report summarises the evaluation of expected effects from blasting operations in the new Weltevreden 381JT project. It is concluded that blasting will be possible but careful consideration should also be given to the recommendations made.

16. Curriculum Vitae of Author

Author joined Permanent Force at the SA Ammunition Core for period Jan 1983 - Jan 1990. During this period I was involved in testing at SANDF Ammunition Depots and Proofing ranges. Work entailed munitions maintenance, proofing and lot acceptance of ammunition. For the period Jul 1992 - Des 1995 Worked at AECI Explosives Ltd. Initially I was involved in testing science on small scale laboratory work and large scale field work. Later on work entailed managing various testing facilities and testing projects. Due to the restructuring of Technical Department I was retrenched but fortunately could take up appointment with AECI Explosives Ltd's Pumpable Emulsion explosives group for underground applications. December 1995 to June 1997 I gave technical support to the Underground Bulk Systems Technology business unit and performed project management on new products. I started Blast Management & Consulting in June 1997. Main areas of concern were Pre- blast monitoring, Insitu monitoring, Post blast monitoring and specialized projects. I have obtained the following Qualifications:

1985 - 1987	Diploma: Explosives Technology, Technikon Pretoria
1990 - 1992	BA Degree, University Of Pretoria
1994	National Higher Diploma: Explosives Technology, Technikon Pretoria
1997	Project Management Certificate: Damelin College
2000	Advanced Certificate in Blasting, Technikon SA

Member: International Society of Explosives Engineers

Blast Management & Consulting has been active in the mining industry since 1997 and work has been on various levels for all the major mining companies in South Africa. Some of the projects where BM&C has been involved are:

Iso-Seismic Surveys for Kriel Colliery in conjunction with Bauer & Crosby PTY Ltd, Iso-Seismic surveys for Impala Platinum Limited, Iso-Seismic surveys for Kromdraai Opencast Mine, Photographic Surveys for Kriel Colliery, Photographic Surveys for Goedehoop Colliery, Photographic Surveys for Aquarius Kroondal Platinum – Klipfontein Village, Photographic Surveys for Aquarius – Everest South Project, Photographic Surveys for Kromdraai Opencast Mine, Photographic Inspections for various other companies including Landau Colliery, Platinum Joint Venture – three mini pit areas, Continuous ground vibration and air blast monitoring for various Coal mines, Full auditing and control with consultation on blast preparation, blasting and resultant effects for clients e.g. Anglo Platinum Ltd, Kroondal Platinum Mine, Lonmin Platinum, Blast Monitoring Platinum Joint Venture – New Rustenburg N4 road, Monitoring of ground vibration induced on surface in Underground Mining environment, Monitoring and management of blasting in close relation to water pipelines in opencast mining environment, Specialized testing of explosives characteristics, Supply and service of seismographs and VOD measurement equipment and accessories, Assistance in protection of ancient mining works for Rhino Minerals (PTY) LTD, Planning, design, auditing and monitoring of blasting in new quarry on new road project, Sterkspruit, with Africon, B&E International and Group 5 Roads, Structure Inspections and Reporting for Lonmin Platinum Mine Limpopo Pandora Joint Venture 180 houses – whole village, Structure Inspections and Reporting for Lonmin Platinum Mine Limpopo Section : 1000 houses / structures.

BM&C is currently busy installing a World class calibration facility for seismographs, which will also be accredited by Instantel, Ontario Canada as an accredited Instantel facility. The projects describe and discussed here are only part of the capability and professional work that is done by BM&C.

17. References

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