Environmental Impact Assessment for Alexander Project

Vibration, airblast and flyrock

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Prepared for

Synergistics Environmental Services

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Executive Summary

A ground vibration, airblast and flyrock study was conducted as part of the environmental impact assessment for the envisioned Alexander mining project.

Ground borne vibration, airblast and flyrock (the latter two during construction phase) was investigated, with the most prominent cause of these effects being blasting. Due to very low charges, these effects are not expected to become a problem. However, blast responses are highly dependent on precise site parameters, operator skills and standoff distances to erected structures and therefore caution should be exercised during blasting.

The risks justify a comprehensive monitoring programme which will deal with ground vibration.

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REPORT LAYOUT

Table 1: Specialist report requirements in terms of Appendix 6 of the EIA Regulations (2014)

A specialist report prepared in terms of the Environmental Impact Regulations of 2014 must contain:	Relevant section in report
Details of the specialist who prepared the report	Appendix D
The expertise of that person to compile a specialist report including a curriculum vitae	Appendix D
A declaration that the person is independent in a form as may be specified by the competent authority	Appendix E
An indication of the scope of, and the purpose for which, the report was prepared	Section 1
The date and season of the site investigation and the relevance of the season to the outcome of the assessment	Section 3.3
A description of the methodology adopted in preparing the report or carrying out the specialised process	Section 4
The specific identified sensitivity of the site related to the activity and its associated structures and infrastructure	Section 5
An identification of any areas to be avoided, including buffers	Not applicable
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;	Section 6
A description of any assumptions made and any uncertainties or gaps in knowledge;	Section 3
A description of the findings and potential implications of such findings on the impact of the proposed activity, including identified alternatives, on the environment	Sections 8 & 9
Any mitigation measures for inclusion in the EMPr	Section 10.1
Any conditions for inclusion in the environmental authorisation	Section 10.2
Any monitoring requirements for inclusion in the EMPr or environmental authorisation	Section 10
A reasoned opinion as to whether the proposed activity or portions thereof should be authorised and	Section 11
If the opinion is that the proposed activity or portions thereof should be authorised, any avoidance, management and mitigation measures that should be included in the EMPr, and where applicable, the closure plan	Section 11 / Section 12
A description of any consultation process that was undertaken during the course of carrying out the study	No consultation required
A summary and copies if any comments that were received during any consultation process	Not applicable, see above
Any other information requested by the competent authority.	None requested

1. INTRODUCTION

Anglo American Inyosi Coal (Pty) Ltd (AAIC) is proposing the construction of a new underground coal mine through the Alexander project, directly to the south- and south-east of Kriel.

This assessment started in 2014, during which background vibrations and air pressure were measured while a blast was occurring at the nearby Isibonelo Colliery. Similarly, blast vibration and sound history data was obtained from the area. This information is considered useful for this report for the following reasons:

I. As a verification check against the geological constants
II. During the construction phase, the airblast and ground vibration data is considered relevant

Though Isibonelo is an opencast mine and the proposed mine an underground mine, data obtained during blasting at Isibonelo is applicable to this project during the construction phase especially shaft sinking, when blasting is also anticipated.

This report provides an opinion on the possible impacts that blasting, hauling and underground mining at the envisioned mine may have on the surrounding community.

2. REGULATORY AND LEGAL FRAMEWORK

In the scientific and engineering literature, standards exist that typically deals with human comfort and structural damage to buildings. The most well-known is the USBM RI 8507 standard by Siskind, D.E., Stagg, M.S. Kopp, J.W and Dowding, C.H (1980), which deals with blasting vibrations and the effect thereof on human comfort and damage to buildings.

The abovementioned standard is however not suitable for continuous vibrations, as typically encountered in construction related vibrations. For this purpose, the Federal Railroad Administration (FRA) provides a comprehensive standard relating to construction vibration. Although the bulk of this document is aimed at high speed rail transport impact assessment, it contains information pertaining to construction vibration that is applicable to generic construction work. In the 2012 edition of this standard (the latest, at the time of this report), the relevant section is chapter 10.

South Africa does not have legislation which limits ground vibration levels (i.e. SANS), nor are there any internal standards (ISO) that limits ground vibrations. Against this background this vibration study is conducted against international best practice, rather than South African legislation. Therefore, there has been heavily drawn upon results produced by the USBM, the FRA, and other research documented in the open literature.

This report complies with the requirements of the NEMA and environmental impact assessment (EIA) regulations (GNR 982 of 2014). The table below provides a summary of the requirements, with cross references to the report sections where these requirements have been addressed.

3. ASSUMPTIONS AND CONSIDERATIONS

3.1. Ground composition

The composition of the ground has an effect on the severity of the vibration propagation due to blasting. As coal is to be mined at the site, it will be assumed that the parameters found in section 5.1 is applicable. See that section for further details.

3.2. Underground mining operational vibrations

Very little information is available about the surface vibrations due to underground mining. However, some information was found regarding underground tunnelling activities. These values were examined and found to compare favourably with the experience – i.e., it's not typically a problem. The values from the quoted sources in that section were therefore deemed to be a good approximation.

3.3. Seasonal and meteorological impacts

Theoretically prevailing meteorological (pressure, humidity, temperature, etc) conditions has an effect on the propagation of sound and vibrations. However, the effect thereof is not expected to be significant for this project – especially since the principle disturbance is expected to be ground-borne vibrations. Ground borne vibrations is not generally accepted to have a measureable dependence on meteorological conditions and no references in the scientific literature could be found. For the sake of completeness, the vibration measurements were performed on the 15th of April 2016.

4. TESTING METHODOLOGY

4.1. Protocol

The measurement protocol followed the procedures and requirements of the ISO 4866:2010 standard. This involved the following:

The background ground vibration measurements involved driving a 300mm stake with a metal base at one end into the ground. This was done to maximise vibration transmissibility to the vibration transducers.

The transducers used were 1000 mV/g ICP seismic accelerometers, mounted tri-axially. These, in turn, was fixed to the metal rod and base by means of a screw that joined the stake and the mounting block. The data was logged by means of a Svantec SVAN958 data logger, which recorded a time domain signal of the vibrations.

Once the instrumentation was set up, the measurement was initiated and continued for a total of ten minutes. During that time, the measurement team stood in one place with as little movement as possible so as to get a representative background vibration measurement.

4.2. Test setup

Figure 1: Illustration of test setup including seismic accelerometers and Svantec data logger

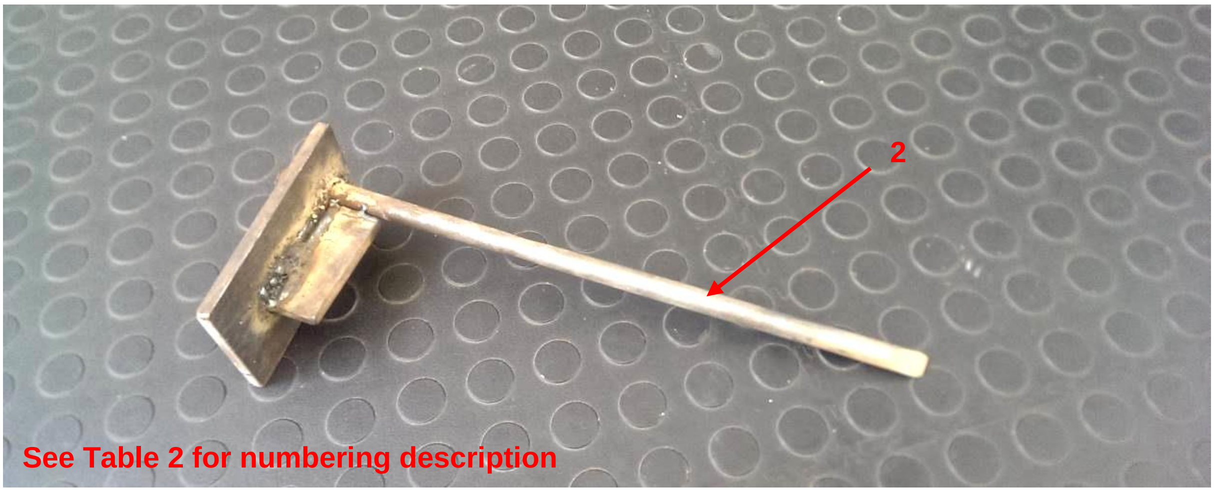

Figure 2: 300mm stake

Table 2: Equipment used for the ground vibrations

No.	Item	Serial number	Details
1	Svantec 958 logger		Resolution: 24bit Sampling frequency: 3.0 kHz
2	Stake		300mm penetration
3	Seismic accelerometer (V)	SN 24743	1097 mV/G
4	Seismic accelerometer (H)	SN 24742	1104 mV/G
5	Seismic accelerometer (H)	SN 25045	1075 mV/G

4.3. Derivation of PPV parameters

$$PPV_{x,y,z} = \max\left(\left|(Signal_{x,y,z}(t)\right|\right) \quad \textbf{Equation 1}$$

$$PPV = \sqrt{(PPV_x)^2 + (PPV_y)^2 + (PPV_z)^2} \quad \textbf{Equation 2}$$

Where $Signal_{x,y,z}$ represents the velocity signals in the x (horizontal 1), y (horizontal 2) and y (vertical) directions. $PPV_{x,y,z}$ represents maximum amplitude values in the x, y and z directions and PPV represents the vector sum of $PPV_{x,y,z}$.

The velocity signals were not directly recorded, but derived from the recorded acceleration signals, as described in section 4 and illustrated in section 4.2.

5. ENVIRONMENTAL IMPACT MECHANISMS

5.1. Ground vibration due to blasting

When explosives are detonated in a hole, it generates shock waves that crush the material around the hole and creates many of the initial cracks required for fragmentation. As this wave travels outward, it becomes a seismic or vibration wave which causes the ground to vibrate. Excessively high ground vibration levels can damage structures. However, even moderate to low levels can be irritating and cause claims of damage and nuisance.

Excessive vibrations can be caused by either putting too much explosive energy into the ground, or by improper design of the blast. The vibration level at a specific location is primarily determined by the maximum mass of the explosive charge that is used in any delay period, and the distance of that location from the blast. A delay of 8 to 9 ms (milliseconds) is usually regarded as the minimum delay between charges, to be considered as separate charges for vibration estimation purposes. Two further factors may also influence the level of ground vibration, namely over-confinement which usually implies excessive burden or excessive sub-drilling. Delays which proceed in sequence along a row, may also cause higher vibrations in that direction (Dick, Fletcher and D'Andrea, 1983). Vibration levels are very intimately related to the precise blast design and in particular also the delays between the detonations of the charges.

Ground vibration levels are usually characterised in terms of peak particle velocity (PPV – see Section 4.3). PPV refers to the maximum amplitude associated with the motion of a particle at the point in the ground which is being considered. Velocity is usually considered because it is best correlated with historical data of damage occurrence: strain induced in ground is proportional to particle velocity. This strain is because of distortion as well as inertial effects.

PPV is usually related to the mass of the explosive charge and the distance to the point of observation. There are numerous empirical relationships, all with a number of empirical site constants, which could be determined through systematic blast tests and subsequent multiple regression analysis. Kujur (2010) provides a useful overview of many of these relationships.

Unless one has prior knowledge of the site constants, the basic problem is to find constants which could be regarded as representative of the condition for which the investigation needs to be done. For this study such constants are not available, and results obtained in a comprehensive set of experiments on a large range of mines, ranging from coal, limestone and iron ore to hard rock mines were used. This study was conducted by the National Institute of Rock Mechanics in India (2005).

Here PPV is modelled as a function of distance from the blast, blast charge and soil constant (note that in the original report there is a typing mistake and the exponent is typed as *b* instead of -*b*):

$$PPV = K\left(\frac{D}{\sqrt{Q}}\right)^{-b}$$ **Equation 3**

In this equation PPV is the peak particle velocity [mm/s], *K* is the site and rock factor constant, and *Q* is the maximum instantaneous charge per delay [kg]. The constant *b* is related to the rock and site. *D* is the distance from the charge [m] and D/√Q is referred to as the scaled distance.

Full details of *K* and *b* values are tabulated in Table 2.1 in the National Institute of Rock Mechanics (2005) report. The basic site constants are summarised in Table 3.

Table 3: Typical site constants for different coal mines

Industry	K	*b*	Plot
Coal	159.12	1.40	
	119.11	1.30	
	185.65	1.33	–
	146.89	1.30	
	534.31	1.63	– –

These sets of constants may be used to provide an uncertainty band for the PPV – charge relationship. Of the constants given above, <u>the third set (plot –) and fifth set (plot – –) yield the worst case scenarios</u>. Implementing Equation 3 for a range of distances from 10 m to 100 m results in Figure 3.

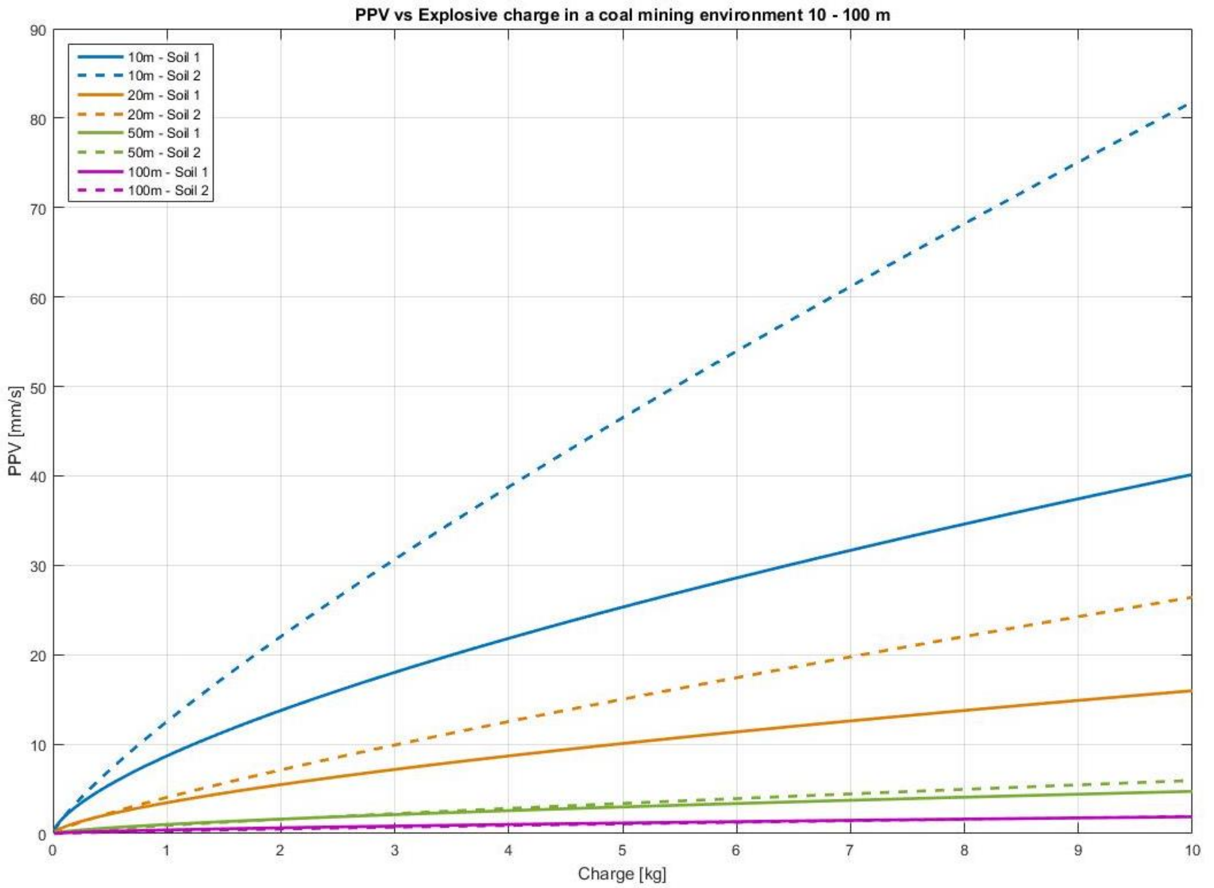

Figure 3: Estimated PPV as function of explosive charge for 10 - 100 m distances

The estimated vibration levels must be assessed against accepted criteria. In this regard guidelines provided by the US Bureau of Mines, are often cited. These are reflected in Table 4.

Table 4: Perceptible ground vibration as reported by US Bureau of Mines

(truncated after adapted by Afeni and Osasan (2009) from Siskind, Stagg, Kopp and Dowding (1980))

Effects on humans	Ground vibration levels [mm/s]
Imperceptible	0.03 – 0.08
Barely perceptible	0.08 – 0.25
Distinctly perceptible	0.25 – 0.80
Strongly perceptible	0.80 – 2.5
Disturbing	2.5 – 7.6
Very disturbing	7.6 – 25.0

Table 5 reports vibration levels which are considered safe for buildings exposed to blasting.

Table 5: Safe levels of blasting vibrations for residential type structures

(Siskind, Stagg, Kopp and Dowding, 1980)

Type of Structure	Ground vibration (PPV mm/s)	
	(<40 Hz)	(>40 Hz)
Modern homes	19.0	51
Older homes, plaster on wood lath construction	12.5	51

From these tables it is clear that residents will find the ground borne vibration disturbing (2.5 – 7.6 mm/s) before structural damage might be expected (in this case probably around 12.5 mm/s). As indicated the levels at which people start to complain about blasting vibrations vary considerably. It is known that these levels are significantly affected by the hostility of the local population and the extent to which their livelihood is dependent on the mine.

Other authorities such as the Australian and New Zealand Environment Conservation Council (ANZEC 1990) specify 5 mm/s as a suggested limit.

An interesting and relevant observation from the Afemi and Osasan study (2009) is the fact that while vibration levels at this mine (in Nigeria) was typically in the range 'Strongly Perceptible' as opposed to 'Disturbing', most of the buildings and structures in the informal settlements were full of cracks and dilapidated. It was observed that most of these structures were constructed with mud and had no concrete foundations. This may have led to uncontrollable absorption of water during the raining season. This emphasises the need for proper photographic records of structures, and continuous monitoring at least until conditions are well understood.

5.2. General construction vibrations

Ground vibration will occur due to construction activities and is typically much less than blasting related ground vibrations. Typical construction levels, in terms of PPV, are provided by FRA (2012) at 7.6m (converted from 25ft) as provided in the source.

Table 6: Reference vibration values at 7.6m of expected construction machinery

Construction machine	PPV at 7.62m (converted to meters from source)
Vibratory roller	5.3
Breaker excavator	2.3
Haul truck	1.9
Jackhammer	0.9
Large Bulldozer	2.3

Approximating the sources as point sources, the following relationship describes the attenuation of the vibration magnitude with increasing distance (adapted from FRA (2012) to yield metric units):

$$PPV(D) = PPV_{ref}\left(\frac{7.62}{D}\right)^{1.5}$$ **Equation 4**

Applying the constants in Table 6 to Equation 4 yields the following figure:

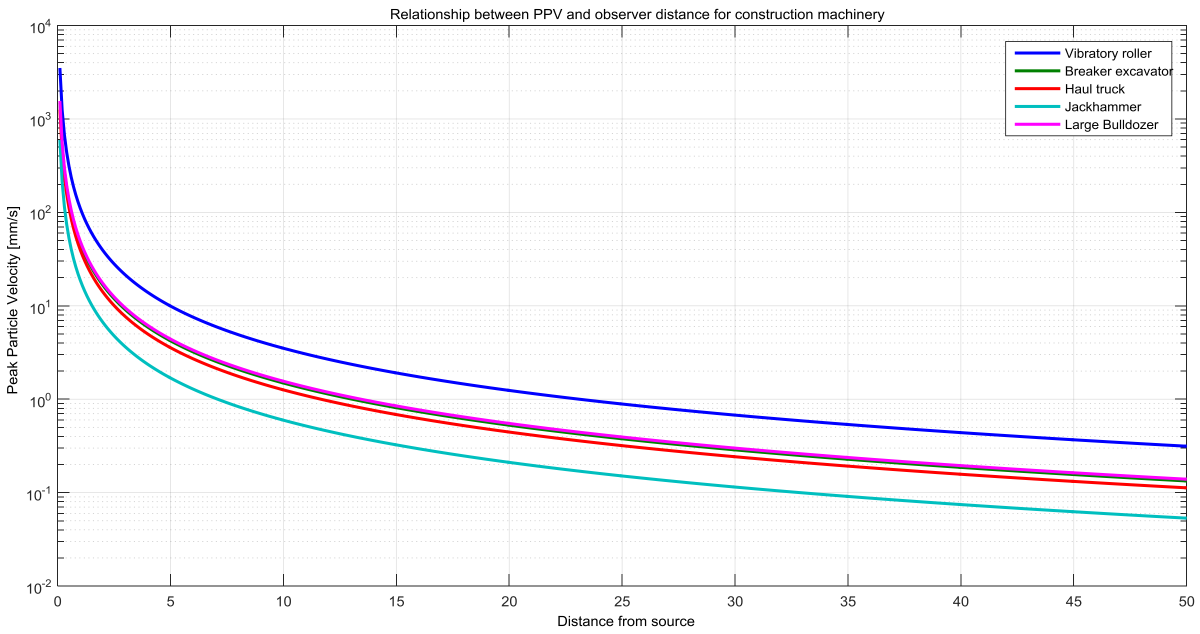

Figure 4: PPV resulting from construction machinery as a function of distance to the source

From FRA (2012) standard, construction vibration damage to structures occurs at a level depending on the type of structure. These criteria are as follows:

Table 7: Vibration damage criteria for different building types

Building category	PPV [converted to mm/s from source]
Reinforced-concrete, steel or timber (no plaster)	12.7
Engineered concrete and masonry (no plaster)	7.62
Non-engineered timber and masonry buildings	5.08
Buildings extremely susceptible to vibration damage	3.05

It can be seen that these criteria differ to a large extent from the criteria proposed by Siskind, et al (1980) in Table 5: the criteria proposed above in Table 7 is somewhat more conservative. The difference is due to the fact that blasting vibrations can be described as an impulse, whereas construction work vibrations has a continuous nature. Consequently, the damage criteria for the two different types of vibration differ considerably.

5.3. Tunnelling vibrations

Vibration resulting from mechanised tunnelling activities can be significant very close to the source, but is rapidly attenuated as distance from the source increases. Although many variables exist that would affect the ground vibrations due to tunnelling, approximate empirical equations have been developed based on a number of case studies. According to Godio et al., (1992 cited in Hillar & Crabb, 2000), the following relationship exists:

$$PPV = Ar^{-1.3}$$ **Equation 5**

Rahman & Orr (2011) suggests the following relationships, based on Equation 5, for upper and lower bounds for various types of soil:

$$PPV = 176r^{-1.18}$$ **Equation 6**

$$PPV = 7.4r^{-1.07}$$ **Equation 7**

Equation 6 and Equation 7 are graphically illustrated in Figure 5.

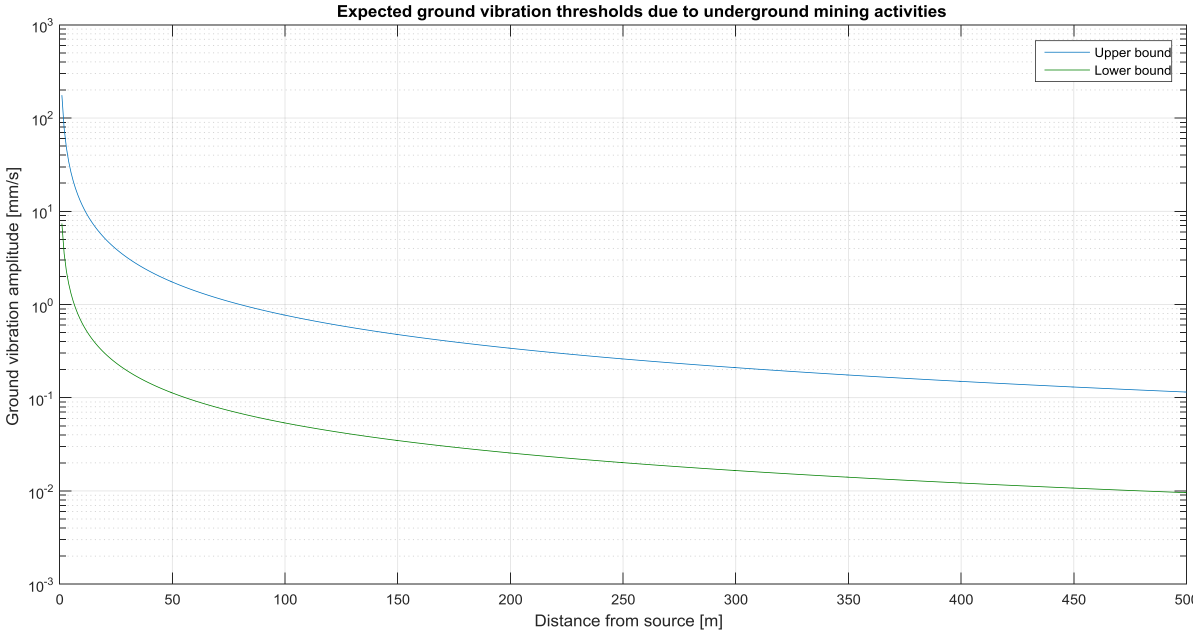

Figure 5: PPV resulting from tunnelling as a function of distance to the source

As can be seen from Figure 5 , in close proximity to the activities, significant vibration amplitudes can be expected, but from about 35m, the vibrations have already been attenuated to approximately 2.5 mm/s.

It must be added at this stage, that the source of this information is from a document detailing tunnelling work from a road construction perspective. However, it can be reasonably expected that the ground dynamics resulting from underground coal mining, using a continuous miner, would behave similarly.

5.4. Flyrock

Flyrock is primarily associated with surface mining and is the most hazardous effect of blasting. During this project, blasting is expected during shaft sinking. Although charges used is much less than mining, it remains a very important cause of onsite fatalities and equipment damage. Kecojevic and Radomsky (2005) indicate that of the 195 blasting accidents which occurred in the US between 1978 and 2001, 27.69% was due to flyrock.

Occasional flyrock will leave a mine site and may cause serious injury and damage beyond the mine limits. Flyrock distances can range from essentially zero for well controlled blasting. However, instances of construction blasting accidents have been recorded where flyrock has reached from 45m (Bjapayee, Verakis and Lobb, 2004) to 240m.

Excessive flyrock is usually caused by improperly designed or improperly loaded blast. To prevent or correct flyrock problems, the blaster should ensure that the burden is proper and that enough collar distance is used. In multiple row shots, longer delays (of the order of 10 ms) between later rows may reduce flyrock.

However, as the current project involves underground mining, this issue is only relevant during shaft sinking (it is however recognised that the charges are substantially smaller than open cast blasting).

5.5. Airblast

Airblast is a transient airborne impulse. The frequency of these blasts are often below 20 Hz in the infrasound range, which means that it cannot effectively be heard by the human ear. People however still sense the blast on their bodies. Research has shown that airblast typically has less potential than ground vibrations to cause damage to structures. Since it however remains a major cause of blasting complaints, airblast should be kept as low as possible.

Figure B-1 from the US Bureau of Mines (Siskind, Stachura, Stagg & Kopp, 1980) depicts airblast overpressure as a function of the cube root scaled distance for various types of mining. Considering an instantaneous charge range of 0.8 kg per delay, it can be shown that the airblast at 500 m may be expected to range somewhere between 86 and 113 dB.

6. POTENTIAL RECEPTORS

Satellite imagery (from Google Earth Professional) as well as guidance from the client yielded several potential receptors representative of the area.

As blasting is typically the most severe source for ground vibrations, the location of the proposed mining areas had a large impact in determining which sites are classified as potential receptors. Consequently, all of the potential receptors are within approximately 1km radius of the mining zones, as sites beyond this point are typically unaffected by ground vibrations (see section 5.1).

Figure 6 provides a map where these locations can be observed. In this map, the yellow pin markers identifies potential receptors, while red circles indicate blast radii (of 1km). These are centred on the potential blasting sites closest to communities.

Table 8: Key sensitive receptors with blasting standoff distances

Location number	Description	Approx. Standoff Distance [m]	Coordinates [D° M' S"]
1	Kriel high school	1000 m	26° 15' 22.52" S 29° 15' 53.04" E
2	Settlement	1200 m	26° 16' 06.10" S 29° 14' 12.17" E

3	Saken Hospitality	~0 m	26° 17' 26.72" S 29° 16' 26.12" E
4	Settlement	~0 m	26° 20' 30.32" S 29° 21' 39.32" E
5	Conveyor route	740 m	26° 17' 45.39" S 29° 23' 58.23" E
6	Homestead	690 m	26° 15' 48.71" S 29° 19' 40.65" E

Location 1 represents Kriel high school, in the centre of the town. Location 2 is a settlement, some distance away from the western most mining zone. Location 3 is a place of accommodation, located within the mining zone. Location 4 is composed of a number of brick and mortar buildings and is part of a small settlement located on the mining zone. Location 5 is a location along the route of the envisioned conveyor belt, where the route crosses the R544 road. Location 6 is on a road just adjacent to a homestead. Note that these locations were chosen so as to be representative of typical structures in the area and were used as the locations to measure the prevailing background vibration. However, a large number of other structures exist within the mining zone. It is however anticipated that the background vibrations at these sites will be of a similar magnitude to values measured in Section 7.

To select these receptors, mining depth was not considered a factor. The reason is that the mining depth is expected to be shallow, roughly 60m, therefore the closest distance to a receptor can be 60m. At this distance mining using a continuous miner and construction vibrations won't be felt. Underground blasting in coal mining would typically use extremely low charges – in the order of 0.5 kg per delay – would results in 0.5 mm/s PPV, according to Equation 3 and Table 4. Though this would be distinctly perceptible it would not be dangerous. Therefore, depth is not considered an important factor in this case.

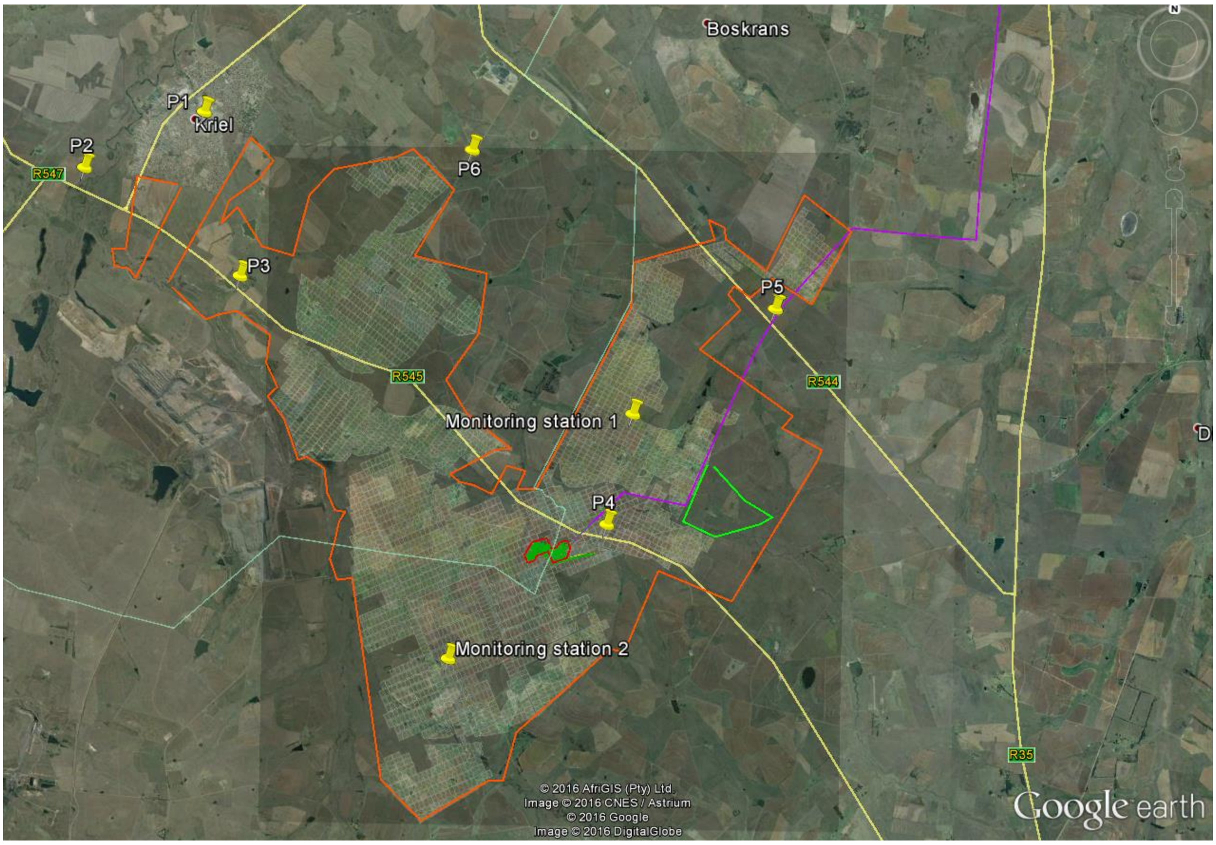

Figure 6: Map of potential receptors (mining plan overlaid)

7. BACKGROUND VIBRATION MEASUREMENTS

Background ground vibration was measured at the location of the potential receptors. During this time, no blasting occurred that the measurement team was aware of. The result is therefore the ambient vibrations. It must be noted that the measurements at location 4 contained unusable data, due to suspected battery failure. However, it is not unreasonable to expect the vibration levels to similar to the other locations

PPV is defined in three axes. An approximation can be made to the worst case PPV by taking the vertically measured vibration value as representative of each direction. This is conservative, as wave fronts in each direction does not arrive at the same time. It is calculated as follows:

Table 9: Background vibration measurements and PPV

Location number	Background measurement [mm/s]
1	0.31
2	0.25
3	1.83
4	-
5	1.57
6	0.53

The table above represent the PPV at the key receptors identified (see section 6). These values are summarised in Figure 7.

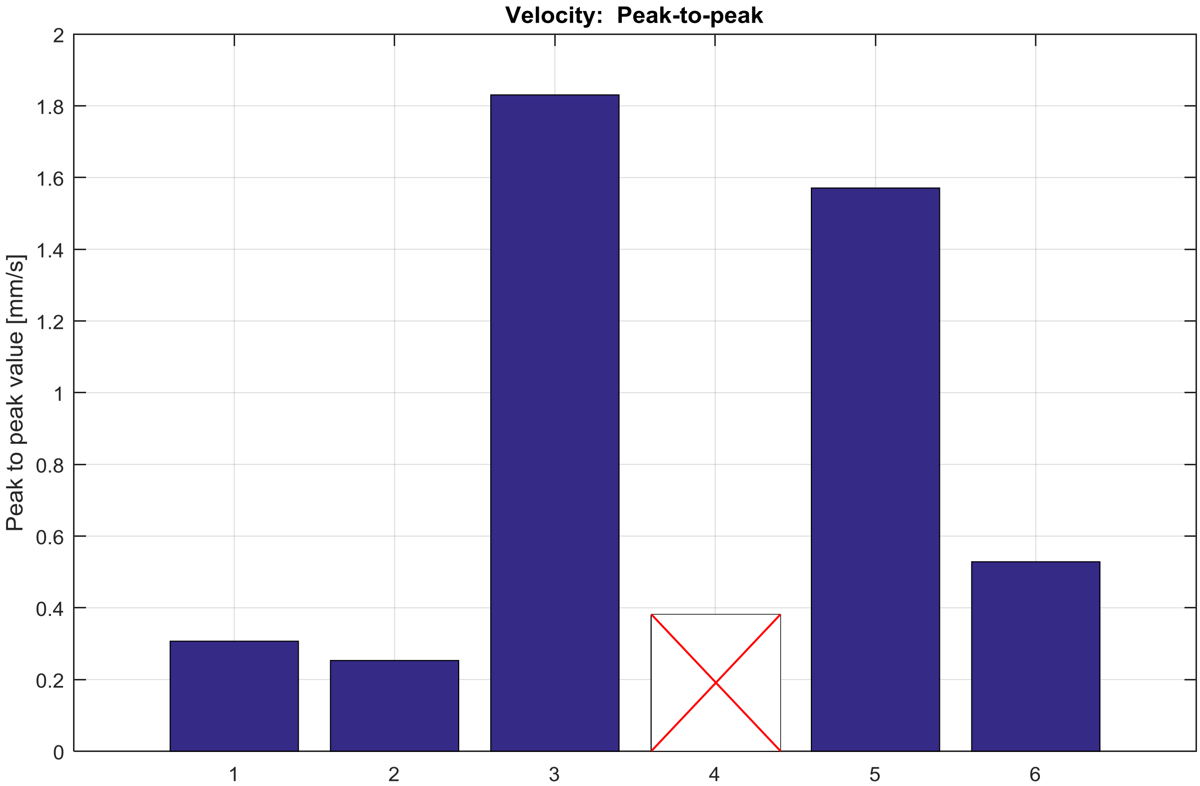

Figure 7: Summary of background vibrations

See Appendix C for photographs and vibration "time-histories" taken during the measurement exercise.

8. DESCRIPTION OF PROJECT IMPACTS

a) Vibration impacts

It is clear from section 5 that blasting vibrations is by far the largest risk, compared to construction and tunnelling vibrations. Nevertheless, vibration impacts due to blasting can be expected to be low due to the fact that the shaft sinking operation requires much less explosives than mining.

When mining using continuous miners, the vibration risk is typically very low. However, if blasting is necessary – and the blast occurs near a community, (60m if the blast occurs right underneath the community) – ground vibration problems may arise if a charge of more than approximately 3.5kg per hole is used.

b) Airblast

Based on Isibonelo experience airblast pressure levels can be expected to be close to acceptable levels. This is likely only to be a consideration during construction phase (notably, shaft sinking) as airblast is not expected to be applicable during underground mining operations. Therefore, an airblast oriented monitoring program is advised during the construction phase.

During shaft sinking, blasting is expected. However, the charges used will likely be very small compared to open cast blasts.

As mentioned in section 5.5, a sound pressure level of 86 to 113 dB is anticipated at a range of 500m (the approximate distance to the closest structure). This is well within the 133 dB limit suggested by the US Bureau of Mines and the 120 dB recommended by ANZEC (1990). Airblasts are however highly dependent on many parameters such as wind direction, temperature inversions, topography, etc.

However, as the current project involves underground mining, this issue is only relevant during shaft sinking.

c) Flyrock

As with airblast, this is not expected to be a risk during underground operations. However, blasting operations during shaft sinking may create a risk of flyrock due to the close proximity of the shaft area (approximately 500 m) to the R545 regional road. Careful blast design is therefore required during this initial period.

9. IMPACT ASSESSMENT

The impacts have been rated in the following manner:

Occurrence

- Probability of occurrence, and
- Duration of occurrence

Severity

- Magnitude of impact
- Scale/extent of impact

The following ranking scales were used (next page):

Table 10: Ranking scales

Probability [P]	**Duration [D]**
5 Definite/ don’t know 4 Highly probable	5 Permanent 4 Long term (full operational life)

3 Medium probability 2 Low probability 1 Improbable 0 None	3 Medium term 2 Short term 1 Immediate
Scale [S] 5 International 4 National 3 Regional 2 Local 1 Site only 0 None	**Magnitude [M]** 10 Very high/ don't know 8 High 6 Moderate 4 Low 2 Minor

The environmental significance was assessed according to the following equation:

$$SP = (M + D + S) \times P$$

Environmental effects are rated according to the following assessment scale:

- More than 60 points indicate a high [H] environmental significance
- Between 30 and 60 points indicate moderate [M] environmental significance
- Lower than 30 indicate a low environmental significance [L].

Table 11: Environmental significance before mitigation

Potential environmental impact	Activity	Environmental significance before mitigation					
		M	D	S	P	TOT	SP
Vibration	Blasting	3	2	1	3	18	L
Airblast	Blasting	3	2	2	3	21	L
Flyrock	Blasting	10	2	2	2	28	L

Table 12: Environmental significance after mitigation

Potential environmental impact	Activity	Environmental significance after mitigation					
		M	D	S	P	TOT	SP
High vibration levels	Blasting	3	2	1	2	12	L
Airblast	Blasting	3	2	2	2	14	L
Flyrock	Blasting	10	2	2	1	14	L

10. RECOMMENDED MITIGATION AND MONITORING

10.1. Mitigation

a) Ground Vibrations

Properly designed blasts generally give lower vibration response per unit explosive mass. These designs typically include using correct burden size and proper delay patterns. Attention must also be given to correct charging procedure and blasting ratios, delayed/micro-delayed or electronic detonators, and specific in-situ blasting tests (Environmental Law Alliance Worldwide, 2010).

The following techniques can be used for mitigation:

- Minimize the charge weight per delay (Afeni and Osasan, 2009). This can easily be done by reducing the number of blastholes fired per delay (Dick, Fletcher and D'Andrea, 1983).
- Avoid overly confined charges, e.g. too much burden or too much subdrilling. (Dick, Fletcher and D'Andrea, 1983).
- Increase the delays between charges. This will however increase the duration of the blast and may cause more adverse reactions from neighbours. (Dick, Fletcher and D'Andrea, 1983).
- Propagate the shot away from the sensitive areas, by arranging the delays correctly (Dick, Fletcher and D'Andrea, 1983).
- Reduce the public perception of vibration by blasting during periods of high local activity, for example shortly after school has been dismissed. (Dick, Fletcher and D'Andrea, 1983).

b) Airblast

Airblast can be reduced as follows (Dick, Fletcher and D'Andrea, 1983):

- Avoid the use of unconfined explosives.
- Ensure sufficient burden strength.
- Compensate for geological conditions which will cause blowouts (e.g. mud seams, voids, etc.).
- Drill holes accurately to maintain the designed burden.
- Reduce or reorientate high free faces which are facing in the direction of built up areas.
- Avoid early morning, late afternoon or night firing when temperature inversions are most likely.
- Avoid excessively long delays that may cause a hole to become unburdened.
- Reduce the public perception of airblast by blasting during periods of high local activity, for example shortly after school has been dismissed.

c) Flyrock

Despite careful planning and good blast design, flyrock still occurs occasionally and must always be protected against. This could be accomplished as follows:

- Adequate blast area security must be maintained (US Bureau of Mines, 1987), based on literature a minimum of 300m is recommended.
- Some margin for error must always be maintained.
- Abnormally long flyrock distances should be measured and recorded for future reference. The size of the guarded perimeter should take this into account.
- Any persons within this perimeter must have safe cover and must be adequately warned.
- US Bureau of Mines surface coal mine regulations prohibit throwing flyrock beyond the guarded zone and more than one-half the distance to the nearest dwelling or occupied structure, and beyond the operators's property line.

It is clear from points a) to c) that mining contractor and blaster play a very significant role in the blasting impact on the surrounding community.

10.2. Monitoring

Due to the low charges used during shaft sinking, air blast and ground vibration is not expected to become a problem during this project. Dedicated monitoring stations are therefore not necessary. However, if incidents are reported by the community should documented.

If exceedances are repeatedly observed, a change in the blast design should be considered (see Section 10.1a). Similarly, repeated complaints should be investigated and if need be, a team should be sent to monitor the vibrations during a blast or operations (whichever is the case). The data from this investigation may be judged according to the criteria in Section 5.

11. CONCLUSIONS

Construction and operational related vibration studies was conducted as part of the environmental impact assessment for the Alexander project.

Although blasting is expected during the shaft sinking phase of construction, the charges to be employed are expected to be much smaller as compared to open cast blasting. With properly designed blasts, the ground vibration and air blast is not expected to cause disturbance to residents. A dedicated monitoring program is therefore not deemed necessary, however any incidents of disturbance or damage should be reported as this may indicate an incorrectly executed blast. This information may assist blasters to employ measures such as precise control of blasting delays and limited instantaneously detonated charges. Fly rock is also not expected to be problem, but the risks justify a security zone.

Once the construction is complete, mining operations are not expected to cause a great amount of vibration or airblast disturbance or danger to the public as underground mining is to be employed unless blasting operations are resumed. In this case, monitoring is once again important.

Therefore, with mitigation measures in place, it is believed that the construction and operation of the mine should be authorised.

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APPENDIX B: BLAST VIBRATION LEVEL MEASUREMENT

As a simple check on vibration levels currently experienced in the vicinity of Project Alexander, vibration control measurements were conducted by Messrs George Breitenbach and Johann Clarke close to the R545 on 28 February 2014. The measurement location is indicated in Figure 8. This location was an estimated 2000 m away from the blasting site at Isibonelo Colliery.

The following data about the blast was obtained from AAIC, via the Synergistics coordinator:

- Area North Strip 26
- Blast 300 m pre-slit blast at 4 m spacing
- 75 holes
- Total charge size 8250 kg at 110 kg per hole

In order to ensure the blast was captured, vibration was recorded over a period of about 6120 s (1 h 42 m) using an eDAQ lite data recorder with a sensitive 10 V/g accelerometer mounted on a beacon in the vertical direction, as indicated in Figure 9. Data was recorded at 10 kHz. The blast was visually observed 6036 s. A microphone was also installed, but also did not provide useful results, due to the traffic noise on the road.

The recorded acceleration history was subsequently processed as follows:

- The data was truncated to focus on the few minutes directly before and after the blast.
- Some detrending was required to deal with drift in the acceleration signals.
- The data was then bandpass filtered over the range 5 to 100 Hz, using a 4^{th} order Butterworth filter.
- The voltage signal was calibrated using appropriate calibration certificates.
- The acceleration signal was subsequently integrated to obtain a velocity signal.
- Acceleration and velocity spectra were calculated as a quality check on the data.

Figure 8: Measurement location

Figure 9: Measurement point

Figure 10 represents the acceleration and integrated velocity signal from 6000 s to 6100 s. At 6036 s (the time the blast was observed) there is some indication of vibration activity. However, one would expect the shock wave to travel over the 2000 m distance over a period of a few seconds. While the wave travelling speed is not known, it is known from the literature that it could be lower or higher than the speed of sound (340 m/s). This suggests that the shock wave should have arrived just after 6040 s.

It is believed that the 6036 s disturbance was due to a vehicle passing. There is another significant vibration peak about 6065 s. This is however far too late to be the shock wave. The signal at 6065 s is again consistent with vibration traces caused by a large vehicle travelling along the road. There was significant (albeit intermittent) traffic on the road during the time of the vibration measurements (see Figure 9).

All indications are that the effect of the blast could not be detected at the observation point, and that the vibration levels due to the blast, as observed at the measurement point, must have been lower than the vibrations caused at this point by passing vehicles (order 50 mm/s) and probably less than the background vibration levels at around 6040 s (2 mm/s).

This is consistent with the observations of the measurement team that they could not feel the blast (although they could see it).

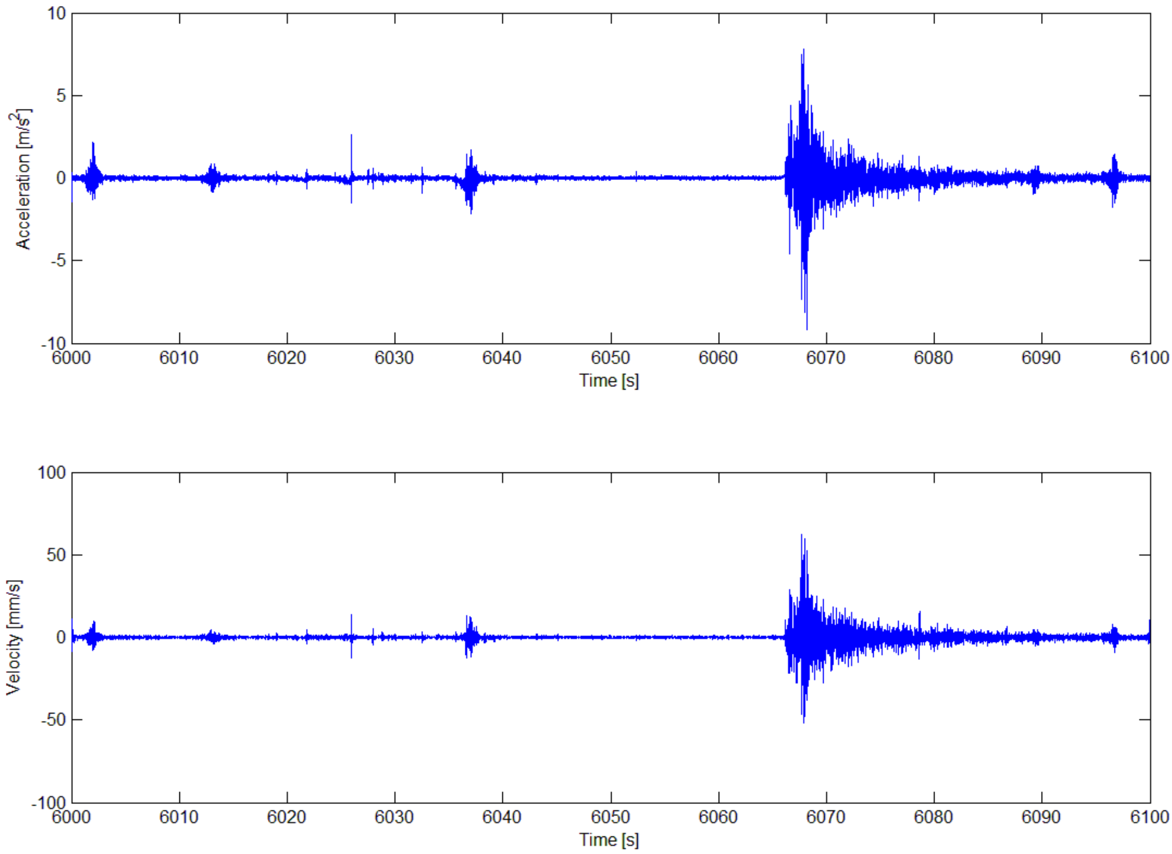

Figure 10: Acceleration and velocity time histories

Using Equation 3 and Table 3 (using the third row of properties), it is clear that at 2000 m away from the blasting site one should expect vibration levels of the order of 0.2 mm/s. This is consistent with the observation that the vibration could not be distinguished from the background vibration (vehicle and other vibrations). While this does not provide enough information to improve the soil wave transmission constants, the observations are at least consistent and provides some confidence in using the soil constants reported in Table 3.

In summary the following conclusions can be drawn from this investigation:

- Calculations based on the ground vibration propagation coefficients provided in Table 3 provide results which are at the very least not inconsistent with observations in the field. These coefficients will therefore be used for the evaluations conducted in the next chapter.
- It is informative (and slightly sobering) to realise that the existing vibration levels caused by vehicles passing through the mining area generated vibration levels at the measurement point which are generally considered as more than 'disturbing' for humans (see Table 4) and

comparable to the limits of structural safety (see Table 5). Although this vibration level will attenuate rapidly with distance

APPENDIX C: BACKGROUND VIBRATION RESULTS

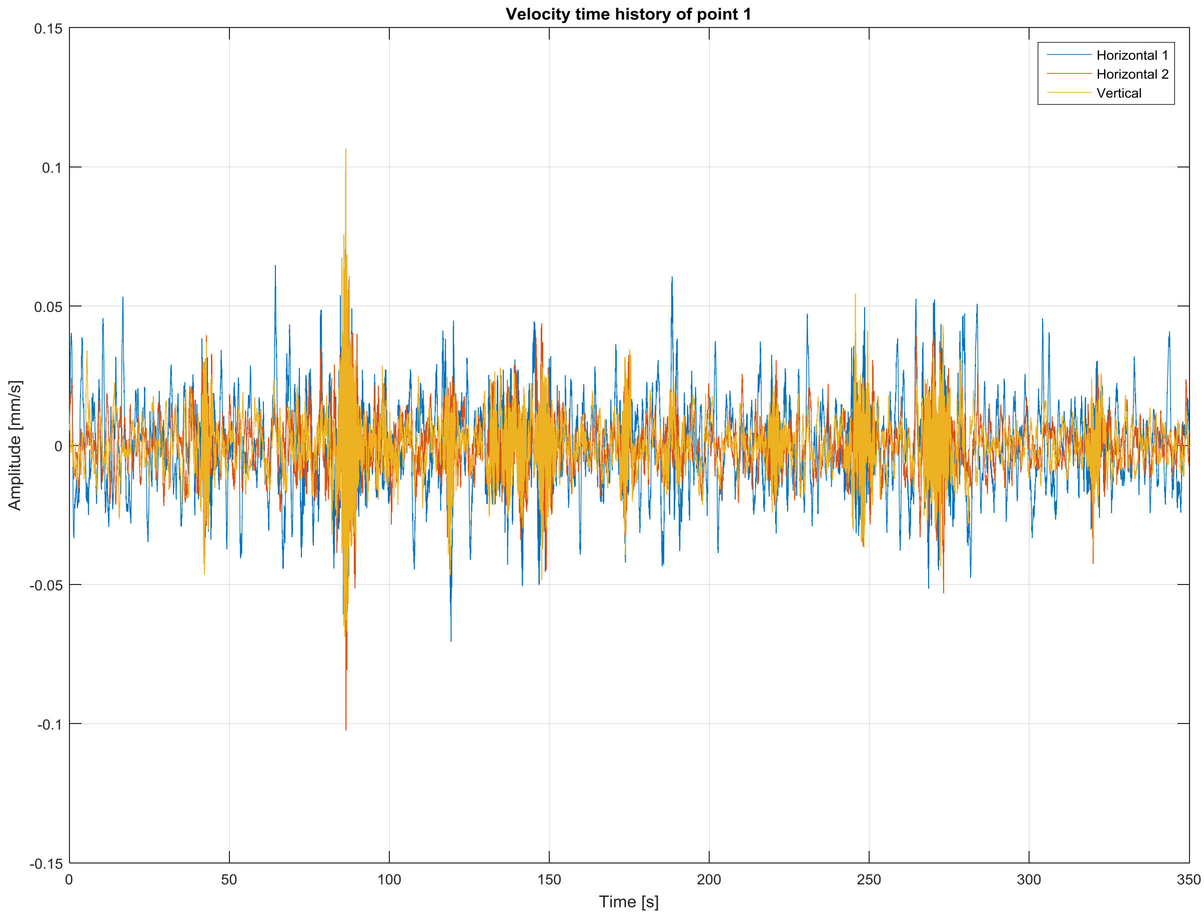

Figure 11: Background vibration measured at point 1

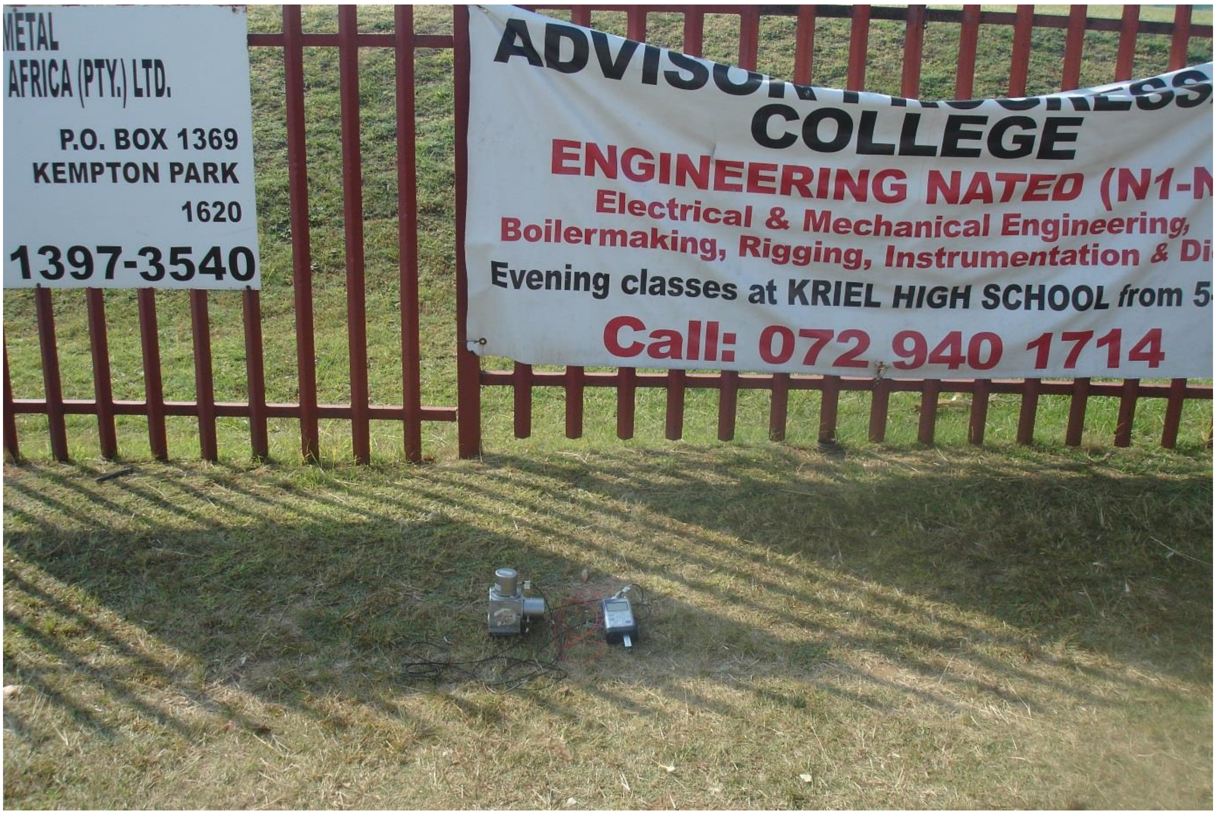

Figure 12: Photo of measurement location 1

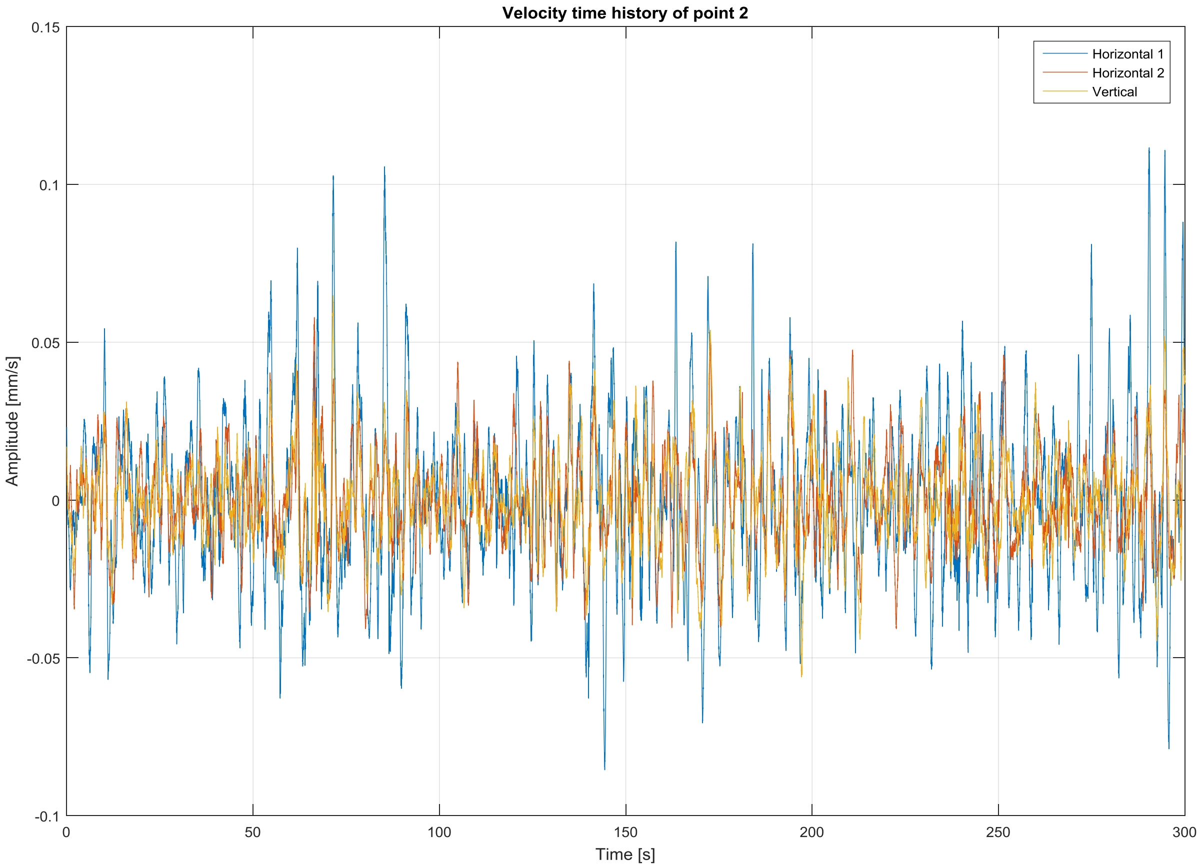

Figure 13: Background vibration measured at point 2

Figure 14: Photo of measurement location 2

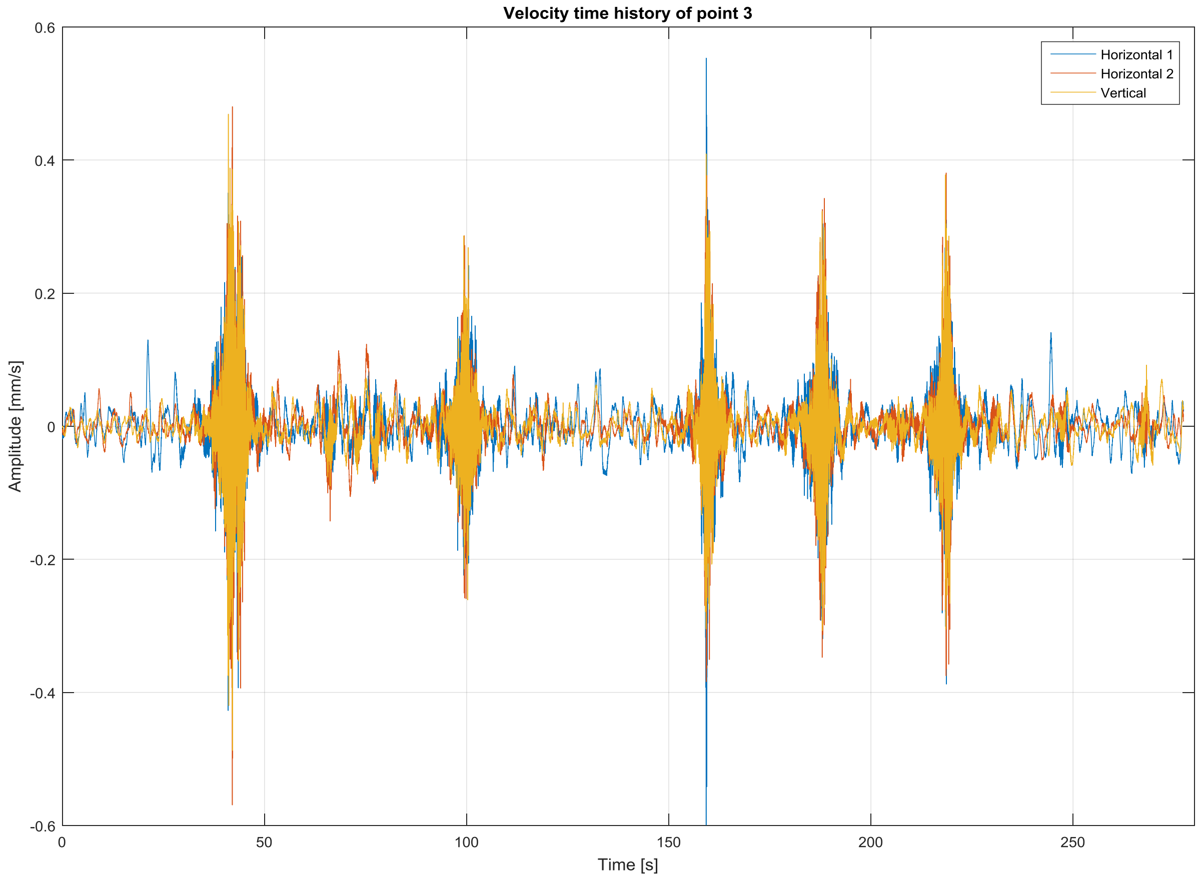

Figure 15: Background vibration measured at point 3

Figure 16: Photo of measurement location 3

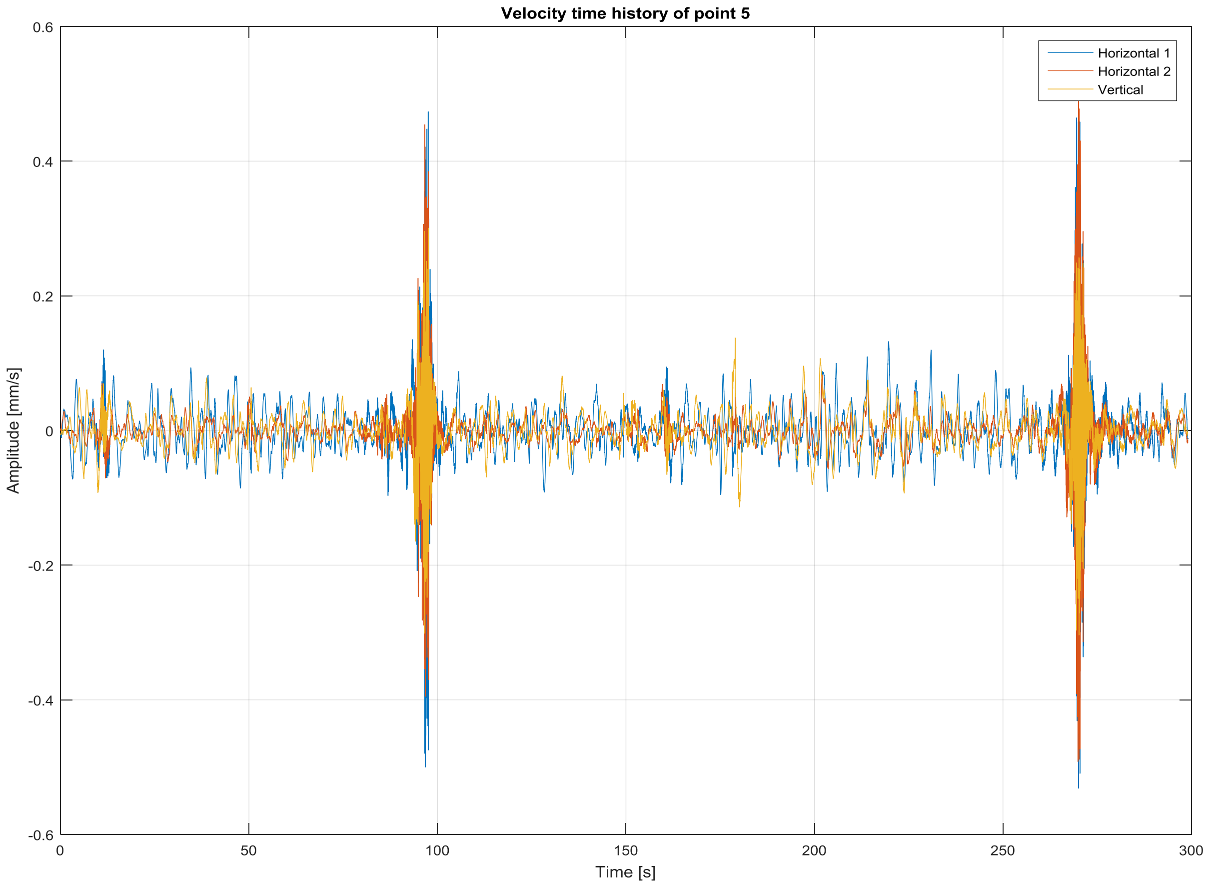

Figure 17: Background vibration measured at point 5

Figure 18: Photo of measurement location 5

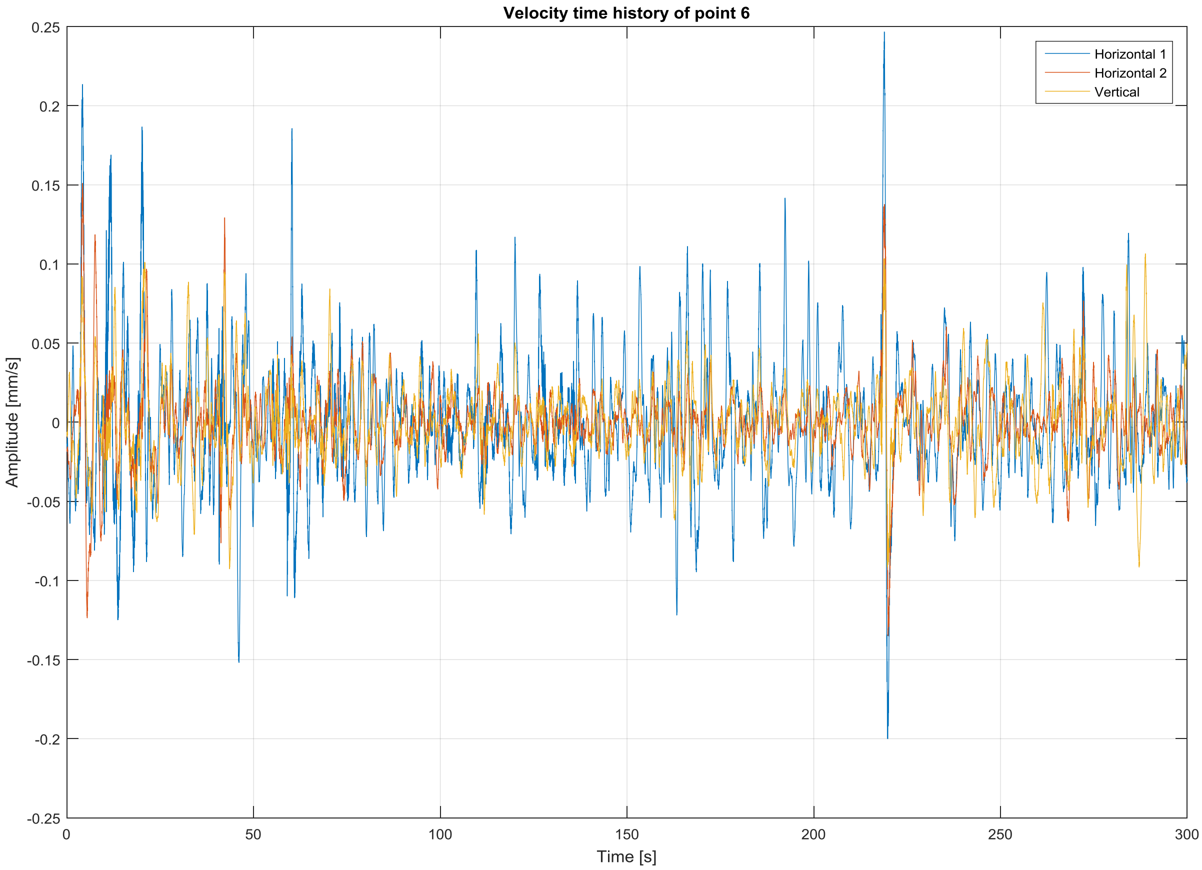

Figure 19: Background vibration measured at point 6

Figure 20: Photo of measurement location 6

APPENDIX D: SPECIALIST DETAILS

Name and Surname	Prof PS Heyns
Role in Project	Supervisory
Citizenship	South African
Qualification	PhD
Registration	Engineering Council of South Africa – registration nr. 860377
Experience in field of expertise	More than 3 decades of experience in vibration and noise related research and specialist consulting projects. Prof Heyns has published more than 65 journal papers in the field as well as about 100 conference papers, most at international conferences. He has acted a project leader for hundreds of industrial projects in South Africa and Abroad. He leads a research team of about 70 people. He is fellow of various South African and international societies, and past president of the Southern African Acoustics Society.

Name and Surname	Mr Rudolph Kroch
Role in Project	Mechanical engineer, specializing in noise and vibrations
Citizenship	South African
Qualification	MEng (Mechanical Engineering)
Experience in field of expertise	7 years' experience analysing noise and vibration problems usually encountered in industrial, mining and automotive applications. Typical projects include: human exposure to whole body vibrations, noise and vibration impact studies, noise and vibration characterisation of plants and machines, vibration based fault diagnosis in machines, airflow pattern measurement and analysis, finite element modelling of noise problems.

RUDOLPH KROCH

Education

2012 – 2015 University of Pretoria (UP) Master of Engineering [MEng] (Mechanical)

2009 – 2011 University of Pretoria (UP) Bachelor of Engineering Honours [BEng Hons] (Mechanical)

2005 – 2009 University of Pretoria (UP) Bachelor of Engineering [BEng] (Mechanical)

Work Experience

Sep 2011 – Present Business Enterprises at University of Pretoria (Pty) Ltd (BE at UP) Provides industry solutions through research and consulting Position: Project engineer

Nov 2007 – Jan 2008 Bateman Engineering Projects SSA Offers project work for the mining, minerals and metals processing industries Position: Student engineer

Dec 2006 Barnie’s Engine Rebuilders – vacation work Apprentice engine builder

Notable Commercial Projects

Human vibration survey on open cast mining machines
Several vehicles were evaluated according to the ISO 2631 standard

Noise and vibration survey in a village near a mine
General noise and vibration root-cause analysis by investigating vibration sound and infrasound

Noise measurement and characterisation of a scrubber in an underground environment
Underground acoustic measurements following the principles of SABS 083

Aerodynamic and noise testing of a continuous miner with integrated scrubber
Two-dimensional mapping of the sound and airflow field around the machine

Finite Element prediction of noise in an underground mining environment
Using the sound power in conjunction with the measured direct field sound of a scrubber, the entire sound field in an underground environment was calculated

Human vibration survey and assessment on a diesel locomotive
Several locomotives were evaluated according to the ISO 2631 standard

Acoustic and vibration analysis on an armoured personnel carrier
In situ sound and vibration was measured on the vehicle in order to identify the source of spurious noise in the vehicle while on the Gerotek test track.

Surface miner vibration survey
Acceleration, sound, vehicle speed and rotor speed of a surface miner were recorded for the client

Roll over protective structure (ROPS) and falling object protective structure (FOPS) tests
Evaluated according to the ISO3471 (ROPS), ISO 3449 (FOPS) and Anglo American 264073 (ROPS and FOPS).

Environmental Impact Assessments
Ground vibration, noise and fly-rock assessments for envisioned industries such as mines, railways and pipelines. No south African legislation exists, therefore assessments are based on international best practices and scientific literature.

Graduate projects

2011 – 2015: Development of a Low Cost vibration monitoring system for industrial gearboxes

A continuation of the project "Development of a prototype vibration monitoring system for industrial gearboxes", the objectives of the projects overlap. The difference is that the goal of the previous project was to develop a prototype, whereas this project aims to develop a production system. The hardware developed in this project seeks to rectify the deficiencies of the prototype and condenses the entire system in a user friendly, PC independent package and introduces several features. More attention is paid to the algorithms to enhance the speed of operation, by means of effort spent on optimising the signal processing techniques used.

2009 – 2011: Development of a prototype vibration monitoring system for industrial gearboxes

Using basic signal processing techniques (Detrending, Windowing and FFT analysis) this project aimed to develop a low-cost, hand held, vibration tester for industrial gearboxes. The challenge in the project was detection of faults in the gearbox with very limited processing power. Starting with a vibration measurement campaign at the SASOL plant in Secunda, representative signals were recorded and algorithms developed, tested and refined in the Matlab environment. Once satisfied, these were translated to C where they were further adapted for the embedded environment. In parallel the prototype specification was generated and component selection took place. Once the electronic hardware was designed (with the help of an electronic development firm) the prototype was tested, first in the SASOL laboratory and then on the SASOL plant. The system worked, but several flaws were identified and corrected with a follow up project, which is the focus of the current project (see above).

Jan – Nov 2009: Wear and tribological investigation of a transfer case

This group project aimed to investigate the tribological aspects of the transfer case of a heavy-duty military vehicle, and to determine the general service intervals. During the project a transfer case was subjected to simulated loads representing normal operation of the vehicle. Oil samples were drawn as well as oil temperature, load and speed measured. After the test, the oil temperature, gearbox loading and gearbox speed were correlated to investigate the correspondence. Spectrographic oil analyses

were performed on the oil samples and correlated with wear on specific transfer case components, such as the roller bearings, journal bearings, casing, shafts and gears.

Jan – Nov 2008: Vibration monitoring and lifetime prediction on a Helical Gearbox

The goal of this project was condition monitoring on a small helical gearbox, where a gearbox was subjected to overloading conditions until failure. The life of the gears was monitored throughout the test with the use of data trending in the time and frequency domain. This was compared to theoretical life calculations of the gear.

STEPHAN HEYNS

Stephan Heyns is professor at the University of Pretoria and holds a BSc(Eng Mech)(1977) degree, an MEng(Mech Eng)(1982) degree and a PhD degree (1987) in mechanical engineering. He is currently director of the Centre for Asset Integrity Management (C-AIM) at the University of Pretoria. This centre focuses on aspects of the physical integrity of mechanical and civil engineering structures systems. His particular expertise lies in the measurement and analysis of vibration of systems, the analysis of the vibration and noise signals and the interpretation of these signals on machine health as well as human health. Prof Heyns has been teaching various courses on undergraduate and post-graduate levels on vibration and noise analysis at the University of Pretoria since 1982. He is particularly knowledgeable on the diagnostics and prognostics of these vibration and noise disturbances in the context of machine health monitoring as well as human health monitoring. Prof Heyns has authored or co-authored more than 65 journal papers in internationally per reviewed journals, as well as more than 100 conference papers. He has also supervised 10 PhD students and about 50 masters degree students in this general field. A full list of publications can be found at

http://web.up.ac.za/default.asp?ipkCategoryID=14193&sub=1&parentid=2163&subid=2164&ipklookid=7

He is a member of scientific committees of various international conferences. He is a C1 accredited researcher with the National Research Foundation in South Africa as well as a fellow of the South African Academy of Engineering, a fellow of the SA Institution of Mechanical Engineers and a fellow of the International Society of Engineering Asset Management.

He is also head of the Sasol Laboratory for Structural Mechanics, at the University of Pretoria. This laboratory does extensive vibration related analysis and testing work for numerous South African and international companies. He has done extensive environmental vibration related projects, which include numerous vibration environmental impact studies and continuous vibration monitoring studies for the Gautrain project, the Coega-Hotazel freight train expansion project, as well as blasting impact studies on many projects in African countries.

APPENDIX E: SPECIALIST INDEPENDENCE DECLARATION

I, Stephan Heyns, declare that –

- I act as the independent specialist;
- I will perform the work relating to the project in an objective manner, even if this results in views and findings that are not favourable to the project proponent;
- I declare that there are no circumstances that may compromise my objectivity in performing such work;
- I have expertise in conducting the specialist report relevant to this project, including knowledge of the National Environmental Management Act, 1998 (Act No. 107 of 1998; the Act), regulations and any guidelines that have relevance to the proposed activity;
- I will comply with the Act, regulations and all other applicable legislation;
- I will take into account, to the extent possible, the matters listed in Regulation 8;
- I have no, and will not engage in, conflicting interests in the undertaking of the activity;
- I undertake to disclose to the project proponent and the competent authority all material information in my possession that reasonably has or may have the potential of influencing - any decision to be taken with respect to the project; and - the objectivity of any report, plan or document to be prepared by myself for submission to the competent authority or project proponent;
- All the particulars furnished by me in this document are true and correct; and
- I realise that a false declaration is an offence in terms of Regulation 71 and is punishable in terms of section 24F of the Act.

Signature of specialist

Company: Enterprises University of Pretoria: Research solutions

Date: 25 May 2016