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Draft

Prediction of Blast-Induced Ground Vibration and Air Overpressure

Spring Hill Gold Project

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1. Introduction

At the request of Martin Costello of Northern Resource Consultants (NorthRes), George Boucher Consulting (GBC) conducted a review of parameters associated with the planned Spring Hill Gold Project (located about 20km North of Pine Creek in the Northern Territory) and developed predictive models for blast-induced ground vibration. These models were used to predict the likely blast-induced ground vibration amplitude for blast conducted in the closest parts of planned pits when measured at adjacent historic underground workings/caves in which Ghost bats reside. These bats are an endangered species and may be disturbed by excessive ground vibration or noise. NorthRes are currently working (and planning work associated specifically for Spring Hill) to develop/assess a link between ground vibration and bat disturbance.

2. Blast-Induced Ground Vibration and Air Overpressure

2.1 Prediction of Ground Vibration

Best Practice for blasting operations is defined within the Australian Standard AS2187.2(2006) which describes the phenomena of blast-induced ground vibration in the following way:

"*Ground vibration from blasting is the radiation of mechanical energy within a rock mass or soil. It comprises various vibration phases travelling at different velocities. These phases are reflected, refracted, attenuated and scattered within the rock mass or soil, so that the resulting ground vibration at any particular location will have a complex character with various peaks and frequency content.*"

The magnitude of the ground vibration, together with ground vibration frequency, is commonly used to define likelihood of annoyance of near neighbours and potential for damage criteria. Studies and experience show that well designed and controlled blasts are unlikely to create ground vibrations of a magnitude that causes damage to structures. AS2187.2(2006) – Appendix J further states:

"*It is recognised that ground vibration and airblast produced by blasting falls into two categories-*

(a) Those causing human discomfort; and

(b) Those with the potential for causing damage to structures, architectural elements and services.

Generally, human discomfort levels set by authorities are less than the levels that are likely to cause damage to structures, architectural elements and services. Ground vibration and *airblast levels are influenced by a number of factors, some of which are not under the control of the shotfirer.*"

Cracks in buildings may be attributable to causes other than ground vibration, including ground or foundation movements (settlement and swell) associated with natural progressive deterioration of buildings over time and/or cyclical expansion/contraction of reactive clay soils during periods of prolonged dry or wet weather.

Many site-based factors including rock type, structure, topography, explosive type, blast design and geometry determine the vibration level that will be transmitted to a particular location remote from the blast location. Consequently the accurate prediction of ground vibration by calculation requires the use of site measurements to quantify the site factors represented in the prediction formula.

The Australian Standard AS2187.2 (2006) Appendix J provides a prediction equation in the form:

$$\mathbf{V = K\,(R/Q^{1/2})^{-b}}$$

Where:

V = peak particle velocity (ppv) in mm/sec

K & b = Site Constants (specific to the attenuation character of the rock between the blast and monitoring locations)

R = Range (distance) to structure (m)

Q = Charge mass per delay (Often expressed as Maximum Instantaneous Charge or MIC) (kg)

AS2187 states that, where no data from previous blasting is available, K=1140 and b=-1.6 are applicable to prediction of mean ppv (i.e. 50% Confidence Limit) for "Free face-average rock" (Refer to paragraph J7.3).

However, the compliance limits set for ground vibration in most mines throughout Australia are usually specified in terms of 90% compliance.

For example, a common regulatory limit of ground vibration in mines is detailed below:

1. the peak particle velocity shall not exceed 5 millimetres per second for 90% of blasts per year;

2. the peak particle velocity shall not exceed 10 millimetres per second for any blast; and

3. no more than one in ten consecutive blasts shall exceed 5 millimetres per second peak particle velocity.

Australian mines are often required to comply with these vibration limits, measured or calculated in accordance with section J4.2 of Australian Standard AS2187.2(2006), for the protection of human comfort at any houses and low rise buildings, theatres, schools and other similar buildings occupied by people. Essentially, the vibration limits apply to sensitive premises.

The Australian Standard AS2187.2(2006) Appendix J specifies that the limit applicable to each type of structure/land use (as shown in the following table taken from the standard):

TABLE J4.5(A)

GROUND VIBRATION LIMITS FOR HUMAN COMFORT CHOSEN BY SOME REGULATORY AUTHORITIES (see Note to Table J4.5(B))

Category	Type of blasting operations	Peak component particle velocity (mm/s)
Sensitive site*	Operations lasting longer than 12 months or more than 20 blasts	5 mm/s for 95% blasts per year 10 mm/s maximum unless agreement is reached with the occupier that a higher limit may apply
Sensitive site*	Operations lasting for less than 12 months or less than 20 blasts	10 mm/s maximum unless agreement is reached with occupier that a higher limit may apply
Occupied non-sensitive sites, such as factories and commercial premises	All blasting	25 mm/s maximum unless agreement is reached with occupier that a higher limit may apply. For sites containing equipment sensitive to vibration, the vibration should be kept below manufacturer's specifications or levels that can be shown to adversely effect the equipment operation

*A sensitive site includes houses and low rise residential buildings, theatres, schools, and other similar buildings occupied by people.

NOTE: The recommendations in Table J4.5(A) are intended to be informative and do not override statutory requirements with respect to human comfort limits set by various authorities. They should be read in conjunction with any such statutory requirements and with regard to their respective jurisdictions.

2.2 Prediction of Air Overpressure

The publication "ICI – Handbook of Blasting Tables" describes a method for prediction of air overpressure. This method is described in the equation below:

$$P = C\,(R/Q^{1/3})^{-1.2}$$

P = pressure (kPa)
C = Constant (determined mainly by level of confinement and atmospheric conditions)
R = Range (metres)
Q = Quantity of explosives (kg per unit time)

Most limits applied to air overpressure are expressed in terms of decibels linear (dBL. To convert kPa to dBL the following equation is used:

$$dBL = 20\,\log_{10}(P/2.0265\text{x}10^{-8})$$

The main challenges inherent to the numerical prediction of air overpressure are:

1. Industry experience has shown that atmospheric conditions exert a high level of dominance upon actual air overpressure results making prediction of air overpressure very difficult.
2. Allowance for the influence of topography and other causes of indirect pathways and wave diffraction.
3. Determination of the constant C. This value must be determined from the degree of confinement of each charge combined with consideration of the atmospheric conditions at the time of firing.

The publication "ICI – Handbook of Blasting Tables" suggests that for "fully confined blasthole charges" in average atmospheric conditions, the constant C = 3.3 (See Appendix D) while for unconfined charges (such as the proposed pilot charge) the constant C = 185.

3. Prediction of Ground Vibration for the Spring Hill Project

3.1 Prediction Formulae and Attenuation Coefficients for Spring Hill

As detailed in Section 2.1, AS2187 provides guidance upon starting parameters for prediction equations where no previous blasting/vibration data exists (such as Spring Hill). However, the 50% confidence limit equation parameters provided offer only a 50% chance of the actual PPV being equal to or less than the predicted PPV – for most projects this is inadequate.

From previous projects where the K and –b factors were found to be similar to the 1140 and 1.6 (respectively) provided in AS2187, GBC has found 90% Confidence K to be about 1800.

Consequently the prediction equation used for these analyses was:

$$\mathbf{V = 1800\ (R/Q^{1/2})^{-1.6}}$$

Where:

V = peak particle velocity (ppv) in mm/sec

R = Range (distance) to structure (m)

Q = Charge mass per delay (Often expressed as Maximum Instantaneous Charge or MIC) (kg)

3.2 Vibration Prediction for Typical Gold Mine Blasts

GBC applied typical blast parameters for Australian Gold Mine blasts to the equation in Section 3.1 and back calculated the minimum distance required for compliance with 2.5, 5, 7.5 and 10mm/s (based upon two holes per MIC event).

Table 1: Predicted Minimum distance for Vibration compliance – Typical Gold Mine blasts

								Minimum Distance for 90% Compliance			
Material and Bench	**Bench Height (m)**	**Hole Diam (mm)**	**Stemming Length (m)**	**Subdrill (m)**	**Depth (m)**	**ANFO (kg/Hole)**	**Pumped Emulsion (kg/hole)**	**2.5mm/s**	**5mm/s**	**7.5mm/s**	**10mm/s**
Fresh Dry Rock	5	102	2.0	0.7	5.7	24	0	423	274	213	178
Fresh Wet Rock	5	102	2.0	0.7	5.7	0	36	518	336	261	218
Transitional Dry Rock	5	102	2.0	0.7	5.7	24	0	423	274	213	178
Transitional Wet Rock	5	102	2.0	0.7	5.7	0	36	518	336	261	218
Oxide Dry Rock	5	127	2.5	0.9	5.9	34	0	503	326	253	212
Oxide Wet Rock	5	127	2.5	0.9	5.9	0	51	616	400	310	259
Fresh Bulk Waste Dry	10	165	3.3	1.2	11.2	134	0	1001	649	504	421
Fresh Bulk Waste Wet	10	165	3.3	1.2	11.2	0	202	1226	795	617	516

NorthRes advised that the distance between bat habitats and planned pits are as close as 85m (horizontal distance to pit edge) and with oxide rock down to about 50m depth, about 150m (horizontal distance to first transitional or fresh rock).

Consequently the predicted minimum distances for typical gold mine blasts are unlikely to comply with any of the PPV limits considered (and selected for analysis by NorthRes).

3.3 Back Calculated Blast Parameters for Compliance at Nearest Locations to Habitats

GBC back calculated the blast parameters required to achieve compliance with the PPV limits nominated for consideration by NorthRes (based upon two holes per MIC event). The following table shows the parameters calculated.

Table 2: Back calculated blast parameters for compliance with 5mm/s at 85 and 150m minimum distance.

									Minimum Distance for 90% Compliance			
Minimum Distance to Habitat (m)	**Material and Bench**	**Bench Height (m)**	**Hole Diam (mm)**	**Stemming Length (m)**	**Subdrill (m)**	**Depth (m)**	**ANFO (kg/Hole)**	**Pumped Emulsion (kg/hole)**	**2.5mm/s**	**5mm/s**	**7.5mm/s**	**10mm/s**
150	Fresh Dry Rock	3	76	1.5	0.4	3.4	7	0	224	146	113	94
150	Fresh Wet Rock	3	76	1.9	0.4	3.4	0	7.4	235	152	118	99
150	Transitional Dry Rock	3	76	1.5	0.4	3.4	7	0	224	146	113	94
150	Transitional Wet Rock	3	76	1.9	0.4	3.4	0	7	235	152	118	99
85	Oxide Dry Rock	2	76	1.8	0.4	2.4	2	0	126	82	64	53
85	Oxide Wet Rock	2	76	1.9	0.4	2.4	0	2	128	83	64	54

Table 3: Back calculated blast parameters for compliance with 10mm/s at 85 and 150m minimum distance.

									Minimum Distance for 90% Compliance			
Minimum Distance to Habitat (m)	**Material and Bench**	**Bench Height (m)**	**Hole Diam (mm)**	**Stemming Length (m)**	**Subdrill (m)**	**Depth (m)**	**ANFO (kg/Hole)**	**Pumped Emulsion (kg/hole)**	**2.5mm/s**	**5mm/s**	**7.5mm/s**	**10mm/s**
150	Fresh Dry Rock	5	89	2.2	0.5	5.5	17	0	353	229	178	149
150	Fresh Wet Rock	5	76	2.0	0.4	5.4	0	16.9	355	230	179	149
150	Transitional Dry Rock	5	89	2.2	0.5	5.5	17	0	353	229	178	149
150	Transitional Wet Rock	5	76	2.0	0.4	5.4	0	17	355	230	179	149
85	Oxide Dry Rock	3	76	2.0	0.4	3.4	5	0	197	128	99	83
85	Oxide Wet Rock	3	76	2.3	0.4	3.4	0	5	201	130	101	84

4. Prediction of Air Overpressure

As is detailed in Section 2, prediction of air overpressure is difficult. Experience at other sites has shown that in most cases, and for well engineered blasts, with good confinement of explosive gas energy, air overpressure at the distances nominated by NorthRes (ie 85 to 150m), can vary between about 95 and 115 dBl.

5. Conclusions & Recommendations

1. Using guidance from AS2187.2, parameters from other comparable projects, inputs provided by NorthRes and typical blast designs from the Australia Gold Industry, it is likely that compliance with PPV limits in the range 2.5-10mm/s will require specialised blast designs at the closest zones within the pits adjacent to bat habitats.

2. NorthRes should continue work to establish a reliable link between PPV, air overpressure and bat behaviour.

3. These analyses have been conducted assuming that 90% probability of compliance with limits is sufficient. Further work should be conducted to assess the influence of infrequent higher PPV events upon bats and if required, higher probability of compliance prediction parameters should be applied.

4. These analyses have predicted the blast parameters applicable to blasting in oxide rock. Some mines blast oxide rock and some dig without blasting (aka free digging). An assessment of the characteristics of oxide rock in the nearest pits should be conducted to establish whether blasting of the oxide rock will be required.

5. These analyses have predicted the blast parameters required for compliance with specified PPV limits at the *nearest* portion of pit volume. An analysis should be conducted to split the pit volumes into zones (defined by distance from the nearest bat habitat) and vibration driven blast designs should be derived for each zone. The blast designs can then costed so as to most effectively assess the cost impacts of vibration restrictions (within the limits of available input data).

6. Air overpressure for blasting in green fields projects is very difficult to predict. The estimates provided in Section 4 should be considered in the context of likely response of bats and further work (including trial blasts at the site to establish both site specific prediction parameters for both vibration and air overpressure) should be considered for later stages of study.

6. DISCLAIMER OF LIABILITY

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Before using the information or blast designs contained in this document in a particular situation it is essential that, amongst other things, the following criteria be taken into account:

- whether the particular technique proposed to be used is appropriate for the circumstances;
- whether the persons using it have the necessary competency and experience;
- the environmental conditions in which it is to be used;
- the specific aims intended to be achieved and whether those aims are achievable in the particular circumstances; and
- the sequence of steps which need to be followed in the particular circumstances.

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