

Protecting Mining Environments from Blasting through Impact Prediction Studies

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Abstract

A surface gold mine wishes to develop a new pit (Pit A) as part of its mining schedules. The proposed pit outline is about 300 m to the closest community. Blasting operations in Pit A would potentially create undesirable environmental impacts including fly rocks, ground vibrations and air blasts to neighbouring communities. Integration of proper planning tools or protocols for blasting at Pit A is the major concern of the Mine. Due to safety reasons, management wishes to explore the best blasting protocols that will restrain any blast impact to a 250 m buffer from the proposed pit outline. The Kuz-Ram fragmentation model was used to generate the optimal geometric parameters required for blasting at Pit A. Ground vibration, air blasts and fly rock impact prediction models were used to estimate the associated blast impacts to the neighbouring community. The predictions were made for blasting the oxides, transition and fresh rock formations to be encountered in Pit A. The predicted ground vibration and air blast levels were compared with the Ghanaian regulatory threshold of 2 mm/s. The predicted maximum fly rock distance (235 m) from the pit outline is within the established 250 m clearance buffer zone. The geometric drill and blast parameters and associated single-hole firing charges were used in the prediction models. The predicted results from this study will assist the surface gold mine to properly execute safe blasting operations with minimal impact to the neighbouring community. Due to known scattering of NONEL explosives in initiation systems, electronic initiation systems are recommended for blasting in the new pit.

Keywords

Blast impacts, Explosives, Blasting, Impact Prediction Models, Geometric Parameters

1. Introduction

Planning the extraction of any mineral deposit requires the consideration of several parameters including but not limited to the quantity and quality of the deposit but also the associated impacts of the mining operations. Hard rock mining is associated with drilling and blasting of the rock formation. In designing blasts in a typical greenfield open pit mine, much attention is given to important environmental and operational factors. The blast must ensure optimum results for the prevailing pit design and mining conditions, while minimizing its effects on the environment. In cases where blasts are conducted close to human settlements, many interests are given to but not limited to the effects of fly rock, ground vibration and air blast. Overall blast efficiency is achieved when blast designs and implementations are properly executed to improve fragmentation whilst minimizing blast impacts. Evaluation of current blasting practices and prediction of blast impacts are keys to the understanding and implementation of blasting systems to reduce any associated blast impacts.

XYZ surface mine wishes to develop a greenfield pit (Pit A) which lies within two main communities in Ghana. The nearest settlement to the proposed pit outline is about 300 m. On-bench blasting would create considerable environmental impacts notably fly rocks, ground vibrations and air blasts. This requires that prior measures are taken to minimize or eliminate these impacts on the surrounding settlements during mining operations and conform to the national guidelines. The Ghanaian Minerals and Mining (Explosives) Regulations, 2012 [1] sub section 176 (1) (a) states that “the minimum safety distance between a blast and a person near the blast site is five hundred meters;” and sub section (2) states that “the minimum safety distance for civil works may with permission of the Chief Inspector be decreased if persons will not be endangered by the decrease”. Sub section (199) of this regulation specifies that the blast vibration and air blast or air overpressure limits should not exceed 2 mm/s and 117 dB (L) respectively. The Mine therefore wishes to integrate proper blasting tools and/or protocols to reduce the associated blast impacts when developing Pit A.

Blast impacts prediction studies were therefore conducted for blasting at Pit A. Due to safety reasons; prediction techniques were used to assess the blast impacts on settlement at a safe distance of 250 m from the pit outline instead of 300 m. The Kuz-Ram fragmentation model was used to evaluate and identify the appropriate geometric drill and blast parameters for the blasting operations of the mine that ensures excellent blast performance (acceptable rock fragment sizes required for the processing plant). The study identifies appropriate measures required for blasting at Pit A that ensure safe blasting operations. Integration of these measures during blasting operations at Pit A is expedient to the success and peaceful co-existence of the mine in the community.

1.1. The Study Area

The gold mining project is located at the south western part of Ghana. The pro-

posed Pit A is an extension of the active mining area of the existing operations of XYZ Mine. The ore deposit comprises generally north-south trending, steeply west dipping auriferous quartz veins hosted by strongly silica and iron carbonate altered, medium to coarse grained, carbonaceous greywacke. A north-south trending dolerite dyke, dipping sub-vertically to the east cuts the depth extension of the main vein.

In the southern portion of the deposit, a west-northwest to east-southeast trending, steeply south-southeast plunging “dyke-like” granitic intrusion is cut by numerous auriferous quartz veins forming a sheeted vein system. In the north of the deposit, mineralization generally occurs in a single lode, but in the south, the mineralization occurs as two main lodes and a series of narrow stacked lodes around or in the outer margins of the granite intrusion. Current interpretation has the main mineralization event occurring post-granite intrusion and prior to intrusion of the dolerite.

1.2. Proposed Mining at Pit A

The total material in bank cubic metres (bcm), which include oxide ore, fresh ore and waste to be mined over the life of the proposed pit (1 year) is estimated as 3.921 Mbcm. The pit will be mined with 6.0 m bench heights over a 3.0 m mining flitch. The deposit will be mined by conventional open pit mining methods, which will utilise open pit mining equipment as listed in **Table 1**. The size of the mining fleet has direct effect on the quantity of rock material planned to be blasted (or mined) over the period and the generation of infinitesimal ground vibrations to the environment. It further contributes to the atmospheric impact of mining (dust, noise) in the environment [2].

The Kuz-Ram fragmentation model [3] [4] [5] [6] was used to assess the geometric parameters proposed for blasting at Pit A. The blast geometric parameters for Pit A have been determined for the oxide, transition and fresh rock zones of the encountered rock formations. **Table 2** shows the evaluation of the proposed drill and blast parameters for Pit A based on the Kuz-Ram model.

1.3. Historic Blast Performance

It was known that, Pit A has similar geological properties as an adjacent active pit of mine XYZ. Due to these similarities, blast performance data obtained from the active pit was used to deduce the blast performance at Pit A. Assessment of historic blast vibration and air blast performances was carried out for the active pit. A total of 144 blasts were monitored and they indicated 85.4% conformance of ground vibration, and 90.3% conformance of air blast values compared to the Ghanaian regulatory threshold limits of 2.0 mm/s and 117 dB (L) respectively. The historic blast performance data of the active pit used as a guide for the estimations are summarized in **Table 3**.

The historic blast performance data shown in **Table 3** indicates the maximum, minimum, and average of the measured ground vibration levels, air overpressure

levels and their associated co-operative charges. The standard deviations of these measurements are further assessed. The historic blast performance data from the active pit were used to establish the site-specific constants in terms of the Rock Transmission Factors (RTF) according to the Gustaffson and the United States Bureau of Mines (USBM) models, and the air pressure referenced from atmospheric pressure (Po). The established site-specific constants for the mine are summarised in **Table 4**.

Table 1. Proposed equipment to be used for mining at Pit A.

TYPE	QUANTITY	APPLICATION
Drill Rig	2	Blasthole/Production Drilling
Liebherr 984 Hydraulic Excavators	1	Excavation and Loading
Motor Grader	1	Grading
Track Dozer	1	Dozing and Pushing
Haulage Truck	4	Hauling
Explosive Truck	1	Bulk Explosives Loading
Water Bowser	1	Dust Control
Service Truck	1	Servicing Machine

Table 2. Evaluation of the proposed blast geometric parameters for Pit A.

PARAMETER	OXIDE	TRANSITION	FRESH
Burden (m)	4.0	3.5	3.5
Spacing (m)	4.0	4.0	3.8
Hole diameter (mm)	115.0	115.0	115.0
Bench Height (m)	6	6	6
Sub-drill (m)	0.8	0.8	1.0
Pattern Type	Staggered	Staggered	Staggered
Final Stemming (m)	3.5	3.4	3.4
RBS of Blend Explosives	142.0	142.0	142.0
Explosive Type (Blend - 30% ANPP & 70% Emulsion)	Emunex8000	Emunex8000	Emunex8000
Explosive density (kg/m ³)	0.0012	0.0012	0.0012
Relative Effective Energy	94.7	94.7	94.7
Drilling Cost (\$/m)	14.25	14.25	9.69
Explosive Cost (\$/t)	930	930	930
Charge per meter, Mc (kg/m)	12.47	12.47	12.47
Charge length (m)	3.3	3.4	3.6
Mass per hole (kg)	41.15	42.40	44.89
Mass above grade (kg)	31.17	32.42	32.42
Technical powder factor (kg/m ³)	0.32	0.39	0.41
Actual powder factor (kg/m ³)	0.43	0.50	0.56

Continued

Mean size (cm)	41.39	36.13	34.68
BCMs per hole (m ³)	96.00	84.00	79.80
Explosives cost per hole (\$)	38.27	39.43	41.75
Initiation cost per hole (\$)	6.83	6.83	6.83
Drilling cost per hole (\$)	96.90	96.90	67.83
Total cost per hole (\$)	142.00	143.16	116.41
Explosives cost per BCM (\$/m ³)	0.40	0.47	0.52
Initiation cost per BCM (\$/m ³)	0.07	0.08	0.09
Drilling cost per BCM (\$/m ³)	1.01	1.15	0.85
Total cost per BCM (\$/m ³)	1.48	1.70	1.46

Table 3. Summarized historic blast performance data of the active Pit.

Number of Blasts (144)	Co-operative Charge (kg/hole)	Air Overpressure Level dB (L)	Vibration Level (mm/s)
Maximum	89	125.5	2.67
Average	52.6	107.6	1.18
Minimum	10.1	98.8	0.13
Standard deviation	19.7	5.5	0.62

Table 4. Site specific constants for Pit A of XYZ mine.

PARAMETER	VALUE	MODEL USED
K	18.773	Gustaffson
k	158.11	USBM
b	-1.153	
Po	1.8721×10^{-8}	$\text{dB}(L) = 20 \log \frac{P}{P_o}$

2. Materials and Methods

The associated open pit undesirable blast impacts are ground vibrations, fly rocks and air blasts or air over pressures. Due to the close proximity and the strong geological correlation between the rock formations at the active and proposed pit, the RTF and Po values deduced from data obtained from the current active pit and the proposed blast design parameters for the new pit were used to estimate the blast impacts when developing Pit A.

2.1. Ground Vibrations Impact Predictions

Ground vibrations are generated when some of the explosion energy released into the ground generates vibration waves within the rock [2]. Several formulae (relationships) are available in literature for estimating the vibration level for a

given site condition, however, the relationships after Gustaffson and the USBM have been widely used [2] [7] [8] [9]. Although, the Gustaffson model was developed in Sweden and the USBM model was developed in the United States of America, according to nation-wide study in the Ghanaian mining companies [7], they have been accepted for use in the Ghanaian mining environment. The Gustaffson model (Equation (1)) and USBM model (Equation (2)) are respectively given as:

$$PPV = K \sqrt{\frac{W}{D^{1.5}}} \quad (1)$$

$$PPV = k \left(\frac{D}{\sqrt{W}} \right)^b \quad (2)$$

where PPV = Peak Particle Velocity, mm/s; W = Cooperating Charge, kg/hole; D = Distance, m; and K , k , b = Rock Transmission Factors (RTF).

With the predetermined RTF values (Table 4) and the various cooperating charges, PPV levels have been estimated for various distances from the blast. The estimated PPV levels according to the USBM and Gustaffson's models are respectively shown in Figure 1 and Figure 2. Table 5 shows the predicted PPV at the corresponding distances for the cooperating charge when blasting in the various formations at Pit A using the proposed geometric parameters.

2.2. Fly Rock Impact Predictions

When fragmented rock resulting from the detonation of explosive charges is transported over a greater distance than anticipated the throw is called fly rock [2]. The maximum fly rock distance for a specific charge $> 0.2 \text{ kg/m}^3$ and the boulder size are estimated according to Lundborg [10] as:

$$L_{\max} = 143 \times d \times (q - 0.2) \quad (3)$$

$$\emptyset = 0.1 \times d^{2/3} \quad (4)$$

where L_{\max} = Maximum Throw (m); d = Hole Diameter (ins); q = Specific Charge (kg/m^3); and \emptyset = Boulder Diameter (cm).

Using Equation (3) the maximum fly rock distance was determined for various blast hole diameters and specific charges based on blast historical records of the Mine. The fly rock model for blasting in Pit A is presented in Figure 3. Substituting the proposed blast hole diameter and specific charges for blasting the various rock zones of the new pit in Table 2 into Equation (3) and Equation (4), the maximum fly rock distances and the associated boulder sizes have been predicted and presented in Table 6. The predicted fly rock distances for blasting the various rock zones of the pit are within the 250 m clearance buffer, and hence although the 300 m buffer neighbouring settlement is less than the established 500 m regulatory clearance buffer for surface blasting operations, the Chief Inspector of Mines could grant permit for mining pit A according to L.I.2177 [1] sub section 176 (2).

Table 5. Predicted PPV values for blasting at Pit A.

Predicted Distance (m)	USBM Model			Gustaffson Model		
	Oxide (41.1)*	Transition (42.4)*	Fresh (44.9)*	Oxide (41.1)*	Transition (42.4)*	Fresh (44.9)*
250	2.31	2.36	2.44	1.91	1.94	2.00
300	1.88	1.91	1.97	1.67	1.70	1.75
350	1.57	1.60	1.65	1.49	1.51	1.55

*Cooperative charges in kg/hole obtained from proposed geometric parameters.

Table 6. Predicted fly rock distances and boulder sizes for blasting at Pit A.

Parameter	Oxide Zone	Transition Zone	Fresh Zone
Specific Charge, q (kg/m ³)	0.43	0.50	0.56
Max Fly rock Throw, L_{max} (m)	148	197	235
Boulder Size, \varnothing (cm)	27.4	27.4	27.4

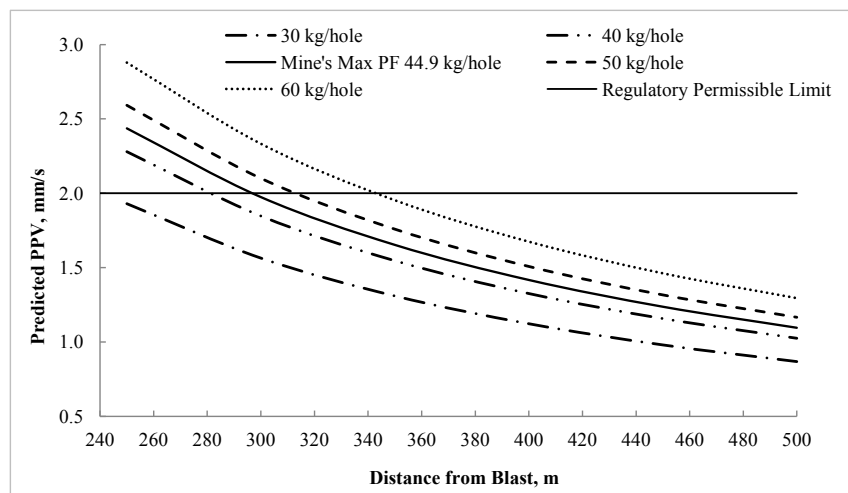


Figure 1. PPV prediction model for Pit A (based on USBM model).

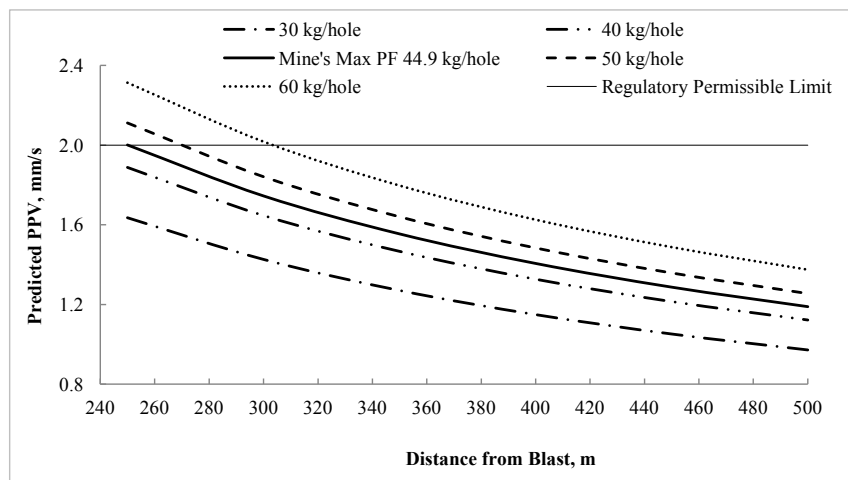


Figure 2. PPV prediction model for Pit A (based on Gustaffson's model).

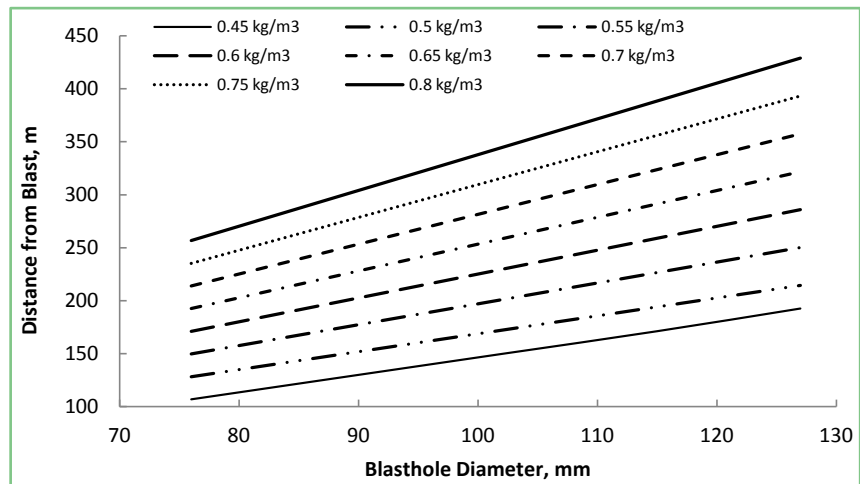


Figure 3. Maximum fly rock throw prediction model for blasting at Pit A.

2.3. Air Blast Impact Predictions

One other major blast effect is the generation of considerable air blasts or air overpressures. Unlike ground vibration, air blast seldom causes damage to structures with the resulting associated noise causing a lot of discomfort and annoyance to neighbours. These usually give rise to community agitations [2] and unrest. The air overpressures were predicted according to Rau and Wooten [11], given as:

$$Lp_2 = Lp_1 - 20 \log \frac{r_2}{r_1} - Ae_{1,2} \tag{5}$$

where Lp_2 = Air Blast for various Distances, r_2 ; Lp_1 = Air Blast at known Distances, r_1 ; and $Ae_{1,2}$ = Attenuation Factor (zero in this instance, thus, *worst case scenario*).

With computed cooperate charges of 41.1 kg/hole (for oxides rocks), 42.4 kg/hole (for transition rocks) and 44.9 kg/hole (for fresh rocks) for blasting at Pit A (Table 2), the predicted air blast at 250 m based on the average historic cooperate charge of 53 kg/hole produces 114.7 dB (L). This is about 2% lower than the regulatory permissible limit of 117 dB (L). The air blast prediction model based on Rau and Wooten [11], using the average historic cooperate charge of 53 kg/hole obtained from blasting operations in the active pit of the Mine adjacent to Pit A is presented in Figure 4.

The air blasts or air overpressures at a blast site may also be predicted using Ollofson [12] and Persson *et al.* [13] shown in Equation (6) and; Holmberg and Persson [14] shown in Equation (7). However, to convert the air blast or air overpressure from mbar to dB (L) units, the relationship in Equation (8) is used.

$$P = 0.7 \times \frac{W^{1/3}}{D} \tag{6}$$

$$P = k \times 0.7 \times \frac{W^{1/3}}{D} \tag{7}$$

$$\text{dB(L)} = 20 \log \frac{P}{P_o} \quad (8)$$

where W = Cooperating Charge, kg/hole; D = Distance, m; $k = 0.75$ for Emulsion Explosives; P = Air Overpressure or Air Blast, mbar; and P_o = Air Pressure from Reference Atmospheric Pressure (determined as 1.8721×10^{-8} unit less for XYZ mine site).

Using a maximum cooperating charge of 44.9 kg/hole from the proposed geometric parameters for blasting fresh rocks at Pit A, the air blast prediction model based on Ollofson [12] and Persson *et al.* [13] model; and Holmberg and Persson [14] model are shown in **Figure 5**.

The maximum predicted air blast based on the proposed blast design geometric parameters for Pit A at varying distances are shown in **Table 7**. It is noted that, the maximum predicted air blast at 250 m from the proposed Pit A is 114.5 dB (L). Blasting at proposed Pit A using the proposed drill and blast geometric parameters would not produce air blast values above the regulatory permissible limit of 117 dB (L).

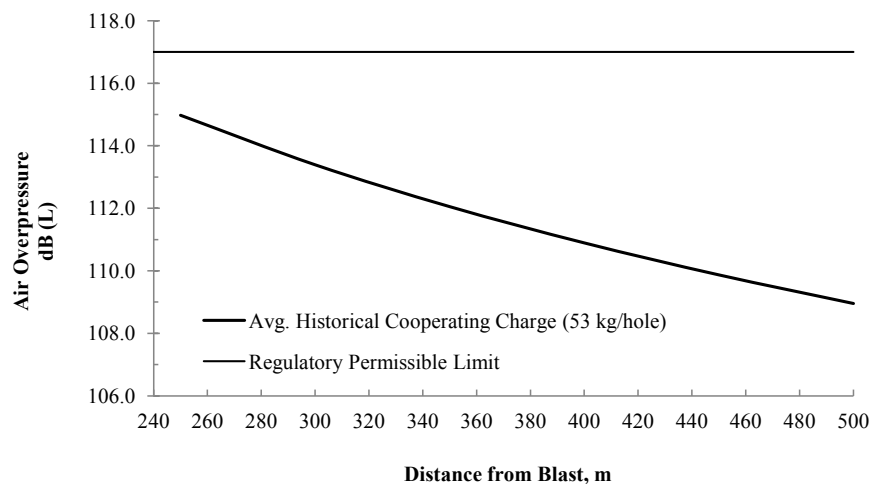


Figure 4. Air blast prediction model for blasting at Pit A (rau and wooten model used).

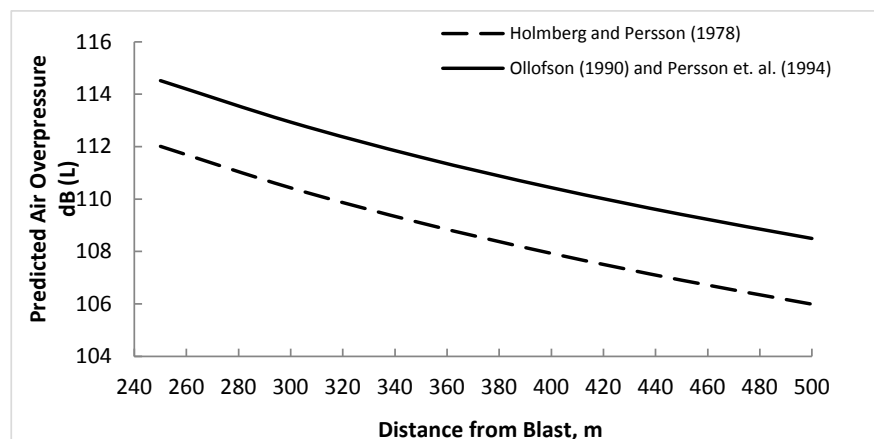


Figure 5. Air blast prediction models for blasting at Pit A.

Table 7. Predicted air blast for varying distances when blasting at Pit A.

Predicted Distance (m)	Ollofson [12] and Persson <i>et al.</i> [13] Model			Holmberg and Persson [14] Model		
	Oxide (41.1)*	Transition (42.4)*	Fresh (44.9)*	Oxide (41.1)*	Transition (42.2)*	Fresh (44.9)*
250	114.3	114.3	114.5	111.8	111.8	112.0
300	112.7	112.8	112.9	110.2	110.3	110.4
350	111.3	111.4	111.6	108.8	108.9	109.1

*Cooperative charges in kg/hole obtained from proposed geometric parameters.

Air blast prediction levels at 250 m when blasting at Pit A for varying cooperative charges have been modeled and shown in **Figure 6**. For the range of cooperative charges (40 - 100 kg/hole), the predicted air blast levels at 250 m using Ollofson [12] and Persson *et al.* [13] and; Holmberg and Persson [14] models are below the regulatory threshold values of 117 dB (L) for residential community.

3. Conclusions and Recommendations

The predictive blast impacts assessment of the proposed Pit A is based on the proposed drill and blast geometric parameters. The associated predictive impact models could be employed for future planning of the mine. The modeling of the fly rock, ground vibration and air blast impacts for blasting operations at Pit A using the proposed geometric parameters and existing geology demonstrated compliance with the mine's established clearance buffer zone as follows:

- 1) The predicted maximum fly rock throw distance of 235 m falls within the 250 m clearance buffer zone established by managements of the mine;
- 2) The maximum predicted PPV at 250 m using Gustaffson model (2.00 mm/s) conforms to the regulatory threshold of 2 mm/s. The predicted PPV using the USBM model is 2.44 mm/s at 250 m but 1.97 mm/s at 300 m; and
- 3) Based on historic data on cooperative charges, for the average cooperative charge of 53 kg/hole, the estimated air blast at 250 m from blasting at Pit A, 114.7 dB (L), is lower than the regulatory threshold of 117 dB (L). Also, based on Ollofson [12] and Persson *et al.* [13] and; Holmberg and Persson [14] air blast prediction models, the predicted air blast levels at 250 m [112 dB (L) and 114.5 dB (L) respectively] from Pit A were below the 117 dB (L) regulatory thresholds.

The prediction models and the predictive values at 250 m from the proposed Pit A are based on the proposed geometric drill and blast parameters and associated single-hole firing cooperative charges of 41.1 kg/hole for the oxide rock zones, 42.2 kg/hole for the transition rock zones and 44.9 kg/hole for the fresh rock zones of the pit. These evaluated cooperative charges should be used during the planning of the blasting operations of XYZ Mine. To ensure practical conformity to these predictions, the maximum cooperative charges together with good

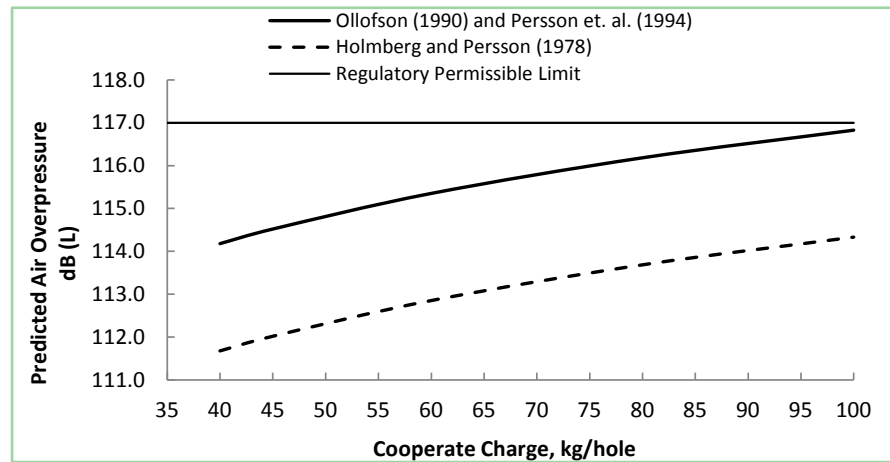


Figure 6. Prediction models for air blast at 250 m when blasting at Pit A.

charging practices should be strictly adhered to. Due to known scattering of NONEL explosives in initiation systems, electronic initiation systems are recommended for blasting at Pit A. Finally, the predicted impact values need to be validated with collected field data during actual mining of Pit A.

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