Establishing Ground Vibration Threshold Level for Open Pit Mining Environment - A Case Study*

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Abstract

To assess the impact of blasting activities on building structures in open pit mining districts in Ghana a study was carried out in Prestea, a township very close to the perimeter of the Plant North pit of the Bogoso Gold Ltd (now Golden Star Resources Bogoso/Prestea Mines), in the Western Region of Ghana. It was observed during the study that the quality of most 'residential building structures within the Prestea township and its environs were generally sub-standard. Most of the houses were in a deplorable state of disrepair with their conditions already triggering failure. Again, it was noted that no records were available to ascertain the structural state of the buildings prior to the commencement of blasting activities at the pit, necessitating the need to carry out a baseline study of buildings in nearby Himan townships for comparative analysis. It was also observed that even though management had selected 12 mm/s as its threshold for its operations in the pits only 6% of the over 542 blasts monitored over a two and half year period had ground vibration values in excess of 1.5 mm/s, with a maximum recorded value of 8 mm/s.

It is recommended that management should not adopt ground vibration levels in excess of 2 mm/s for their pit operations because of the poor infrastructure within the surrounding communities. Even though this level can increase drilling and blasting costs considerably, it is considered a better option than expensive lawsuits in the likely event of any further damages that may be caused to building structures in the township.

1 Introduction

An assessment of buildings in some mining districts in Ghana where blasting activities simulate strong ground vibrations require thorough appraisal. Damage caused to the building structures in these areas cannot be attributed to a single cause alone. There are several causative agents such as: poor building materials quality, poor, foundation problems, differential settlement, ground vibration, ageing and building maintenance culture. The ground vibrations from the extensive open pit blasting activities can however, worsen the already precarious conditions of the buildings or they can act as catalysts to worsen the already deplorable state of the structures. To assess the impact of blasting activities on building structures in open pit mining districts in Ghana a study was carried out in Prestea, a township very close to the perimeter of the Plant North pit of the Bogoso Gold Ltd., (now Golden Star Resources Bogoso/Prestea Mine), in the Western Region of Ghana.

Golden Star Resources (Bogoso/Prestea) Ltd. owns and operates a combined mining lease covering an area of 224 km^2 at Bogoso and Prestea, known as Bogoso/Prestea Mines. These concessions are located in the Wassa West District of the Western Region of Ghana. The Bogoso/Prestea Mines employ open pit mining operations, one of the main pits is known as Plant North Pit (PNP), at Prestea. In addition to the surface operations there is also the Prestea underground mine (New Century Mine) which is currently under care and maintenance. At the time of this study, the only operating open pits of the Golden Star Resources (GSR) were the Plant North Pit at the Prestea Township and the Ablifa pit at Kwame Niampa village. The Prestea Plant North pit is located about 300m to the east of and parallel to the general layout of the Prestea Township.

1.1 Conflicts between Residents of Prestea Township and the Mine Management

Since blasting activities started at the Plant North Pit in January 2003), the inhabitants of Prestea Township living close to this pit have complained of the development of cracks and general deterioration in their buildings, damages to electrical and electronic appliances and general nuisance by way of fright and noise. The people have attributed this to the adverse impacts of blasting at the nearby Plant North Pit.

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It was the initial view of the mine management the effects of the blasting operations in the pit were not causing what the people complained about as they had been monitoring their blasts since they began blasting in the pit. The results of the blast monitoring showed that the levels of ground vibrations from these blasts generally fell below the United States Bureau of Mines (USBM) threshold limits of 12 mm/s adopted for their operations. Management therefore took no positive steps to address the complaints of the inhabitants.

After receiving no positive response from the mine management on their complaints the inhabitants resorted to a series of demonstrations against the Company (Anon, 2003). The impasse culminated in the temporary suspension of blasting operations at the Prestea pit by the Environmental Protection Agency (EPA) in October 2005. This action was deemed necessary to enable the mine management address concerns raised by the people and to find an amicable settlement between the two parties.

During this period of suspension of blasting activities the management sought for professional opinion on the matter. This paper presents the findings of such a study. The work included an assessment of the blasting activities at the pit to determine the ground vibration levels generated using various quantities of explosives, an assessment of the conditions of the building structures in the various communities of the Prestea township and the determination of a threshold value of ground vibration with the corresponding quantity of explosives to be employed for carrying out the blasting activities that would produce minimal adverse environmental impact on the Prestea township and its environs.

2 Drilling and Blasting Activities at the Prestea Plant North Pit

Drilling operations are undertaken by the mine's own personnel while African Explosives Limited (AEL) supplies the required explosives and carries out the charging, blasting and blast monitoring operations on contract for the Golden Star Resources (GSR) Bogoso/Prestea Ltd.

Tamrock drill rigs, using 89 mm and 102 mm diameter drill bits, were employed for all drilling operations from the onset of blasting operations in January 2003. These were however, replaced with the Atlas Copco L7 drill rigs, using 115 mm diameter bits, in April 2005 and which were in turn eventually replaced with a smaller diameter bit of 105 mm in October 2005.

Blast holes were generally, drilled vertically with the holes at the edges of the benches being inclined at 60^o to 65^o Before the disturbances of September 2005 an average of up to 200 holes were drilled for each blast per paddock or section. This number was however, reduced to 100 holes per blast per section with up to 3 sections being blasted per blast or shot. This reduction was necessitated by the need to reduce ground vibration levels to meet the environmental requirements at the Prestea township. Bench heights have been designed for 8.0 m with subdrilling of 0.5 m for all material types in the pit. Operational bench heights however, varied between 4 m and 12 m, depending on prevailing site conditions.

The method for charging of blast holes was column loading, using 150 g cartridges of pentollite explosives [called 'booster' on the mine] with 500 ms in-hole Unidet NONEL detonators as primers. Between 25 kg and 60 kg of bulk emulsion explosive was then pumped into the holes and the remainder of the blast hole (about 2.2 m in length) filled with either drill cuttings or 12 mm quarry chipping as stemming material. Table 1 shows blast design parameters for the pit. 25 ms surface delay detonators were used between blast holes in a row and 67 ms between rows of holes.

Table 1 Blast Design Parameters Used at the Prestea Plant North Pit

Type of Material	Oxide Ore	Transition Ore	Sulphide Ore
Density Material (t/m^3)	1.90	2.10	2.65
Drilling Pattern	4.5"5.0"8.0	3.5*4.0*8.0	3.0*4.0*8.0
Bottom Charge (g)	150	150	150
Column Charge (kg)	25	30-40	40-60
Total charge /hole (kg) Specific Charge	25.15	30.15-40.15	40.15-60.15
Powder Factor (kg/m^3)	0.20	0.30	0.54

3 Structural Defects

The structural defects on the dwelling houses varied considerably with the type of house and mode of construction. The houses are categorized into four principal units namely, wattle and daub houses, mud buildings, landcrete, and sandcrete houses**.** The foundation footings for most of these structures are often either very shallow or absent with poor quality building materials. The buildings are thus vulnerable to various defects that include associated foundation problems, poor building material quality, bad building maintenance culture, differential settlement and ground vibrations.

Associated foundation problems within the settlement resulted from factors attributed to poor foundation footings, shallow foundation depths, and seasonal weather changes, removal of vegetation cover, intensive surface run-offs, earth flow and clayey soil conditions. Most of these buildings have no drains around them and as there is little or no vegetation cover the foundations have been severely eroded resulting in the virtual suspension of many of structures.

Maintenance work on buildings has to be predictable (i.e. regular periodic work as and when necessary) or avoidable (i.e. required to rectify failure). Failure to engage in early repair work could result in eminent structural collapse (Fig. 1). It was noted most of the buildings within the settlement had not been given any major repairs or maintenance for a very long time while some of the structures had been left at the mercy of the weather.

Fig. 1 A Landcrete House with Distressed Foundation

All elements of buildings deteriorate at a greater or lesser rate depending on material quality. This is one of the critical causes of early deterioration of structures. Also the quality of materials used, mode of construction and environmental conditions of the buildings made them suffer severely from the harsh weather conditions. Accordingly they responded quickly to the fluctuating effects of the high rainfall pattern and the scorching sun prevalent in the area, thus inducing differential settlement. According to Seeley (1985), buildings may suffer differential settlement for a variety of reasons including inadequate foundation, low bearing or shrinkable clay soil, presence of trees close to the footing and the effects of mining activities close-by.

Vibrations in buildings could be generated from machinery, transport and, to a lesser extent, noise within the settlement. It may become objectionable to people and interfere with their work. In the Prestea township the prevalent source of vibrations is attributed to the activities in the nearby open pit mine. Although investigations by building and road research establishments show that the risk of damage to normal buildings by vibration is extremely small (Seeley, 1985), blast vibrations from the pit may have compounded the already precarious situation at the township (Fig. 2).

Fig. 2 Serious Multiple Crack Damage in Building Attributed to Blasting

4 Results and Discussions

This section discusses the procedure for estimating ground vibration threshold levels for the Plant North Pit at Prestea, using pertinent literature and the results of over 542 blast monitored activities within a period of two and half years.

4.1 Predicting Ground Vibration Levels Using Plant North Pit Blast Design Parameters

Ground vibrations due to blasting are generated when some of the released explosive energy during detonation generates seismic waves within the rock mass. The vibration level may be measured in such parameters as peak particle velocity (ppv), in millimeters per second, displacement in mm, acceleration in mm/s^2, etc. Generally, the most used parameter for assessing damage to buildings is the peak particle velocity (mm/s). For a given site or location a correlation exercise could be carried out to determine the most suitable relationship for estimating the peak particle velocity generated.

The environmental acceptability of the blast design parameters in Table 1 was established by using design parameters generated by the company. The results obtained were then compared with a National Standard (Threshold) and other values from actual monitoring activities. The impacts of these blasts on the nearby buildings at the Prestea township and its environs were then assessed by studying the physical conditions of the buildings. According to Oloffson (1990)

ground vibration levels (V) may be estimated using the following relationship:
$V = K \{Q / R^{3/2}\}^a$

Where
a = 0.6 determined for the Plant North Pit of Prestea.
V = ground vibration, (mm/s),
Q = maximum weight or cooperating charge, (kg), instantaneous charge
R = distance of blast from the monitoring point or structure, (m) and,
K= Rock transmission factor (RTF) for the area. It is a parameter that characterizes the homogeneity of the rocks in the blast area and its environs.

For predicting ground vibration levels from the various blast design parameters at Plant North Pit at Prestea the average value of "K" in equation (1) was found to be 59, when monitored results of blasting activities together with their corresponding co-operating charges and distances of the blast faces from the monitoring points were used (Table 2) the Rock Transmission Factor (RTF) value obtained compares favorably with the value obtained previously for the erstwhile Satellite Goldfields Ltd (now Golden Star Resources, Wassa Mine), (Anon 2002). The Golden Star Resources (Bogoso/Prestea mine) and Golden Star Resources (Wassa Mine) are both located on the Prestea-Ashanti Gold Belt with similar lithological units.

Table 2 Rock Transmission Factor (K) Determined for Prestea Plant North Pit Average Rock Transmission Factor =59

Vibration Levels (mm/s)	Co-operating Charge (Kg)	Monitoring Distance from face (m)	Rock Transmiss-ion Factor (K)
2.54	70	400	43.61
2.03	60	300	29.51
1.78	70	300	23.59
7.37	77	400	119.52
1.65	60	440	33.86
1.78	24	410	59.4
2.27	50	370	44.47
1.65	56	400	32.39
3.68	35	310	76.14
2.03	35	300	40.78
3.43	56	440	73.36
3.68	40	300	68.24
3.17	40	270	53.46
6.35	40	200	81.75
2.29	32	360	57.2
2.48	35	300	49.82
4.83	22	320	135.87
2.54	45	360	51.71
2.73	24	200	47.75

On hand with the Rock Transmission Factor (RTF) in Table 2 and equation (1) ground vibration levels have been estimated for the various blast design parameters and are summarized in Table 3. From Table 3 it can be observed that the established blast design parameters generated ground vibration levels of between 2.4 mm/s and 4.1 mm/s on structures within an average distance of 300 m from the blast face, provided that laid down procedures are strictly applied at the pit. This implies that structures beyond 300 m would be subjected to far lower vibration levels.

Table 3 Predicted Ground Vibration Levels for the various Blast

Type of Material	Oxide Ore	Transition Ore	Sulphde Ore
Blast hole dia (mm)	**115 and 105**	**115 and 105**	**115 and 105**
Bench height (m)	**8**	**8**	**8**
Distance from face (m)	**300**	**300**	**300**
Co-operating charge (kg)	**25.15**	**30.15-40.15**	**20.15-60.15**
Predicted ground vibration Levels (mm/s)	**2.4**	**2.69-3.19**	**3.19-4.10**

4.2 Assessing Impact of Blasting Activities from the Plant North Pit on Prestea Township and its Environs

Records on the mine show that most of the blasts carried out at the pit between January 2003 and September 2005 were monitored for ground vibrations and air blasts. A total of 542 blasts were recorded and out of this only 20 blasts (representing about 6% of total blasts) had ground vibration levels above 1.5 mm/s while 9 blasts had air blast values in excess of 120 dB(L) which is the recommended Environmental Protection Agency (EPA) of Ghana levels. The records also show that attention was not paid to Frequencies (at vibration levels were recorded) and the weather conditions at the times of the monitoring exercises. Frequencies and weather conditions are important parameters when assessing the damage potential of a particular blast in terms of ground vibration and air blast. According to Konya and Walters (1990), frequency is an important factor in assessing the damage potential of vibrations as structural resonance lies in the low frequency range typically of 5 to 20 Hz and blast vibration in this frequency range can cause a resonance response in structures which produces increased displacement and strain, giving serious problems in the structures. Also air blast levels rise with increased overcast skies with a corresponding increased damage potential.

4.3 Assessing Damage Conditions of Building Structures in the Prestea Township

At the time of this study, Mine Management had not carried out any assessment of the conditions of the houses in the blast area before starting blasting and other mining activities. Some base line information was needed to help in the blast damage assessment in the study. Some base line study was carried out at Himan, a nearby village with similar building structures and which had not been subjected to any impacts of blasting from the Prestea pit, to provide the necessary data for a comparative damage assessment of the Prestea buildings.

Assessment of damage caused by ground vibration due to blasting at the Prestea township and its environs is a complex process. The magnitude of structural damage caused to building structures resulting from blasting activities appeared to be disproportionately high, considering that over a two and half year period only about 4% of total blasts monitored had ground vibration levels higher than the 2 mm/s established threshold. Experts on the subject of blast damage due to ground vibrations generally agree that most structures have cracks of some kind, from other sources than blast vibrations. These are usually due to causes ranging from poor construction to normal environmental stresses such as thermal stresses, humidity, wind etc. It is unusual to find a house without a crack in it. However, when any blasting is undertaken in the area environmentally induced cracks are quickly attributed to it. Most of the cases in the Prestea township fall into this category.

It is a fact that vibration damage due to blasting can and does occur but blasting operations nowadays are usually so engineered and controlled that genuine cases of blasting damage are generally very small and in the minority. Konya and Walters (1990), point out that there will always be structures at the point of failure due to normal environmental stresses waiting for the proverbial "straw that broke the camel's back" and this straw may be the vibration caused by nearby blasting activities, even though in reality it may not be the actual cause.

The above points notwithstanding, it cannot be ruled out that some damage must have been caused to some of the houses at the Prestea township as a result of blast vibrations. It is difficult to point out such houses without thorough investigation. However, the assessment process would have been easier if a baseline study had been carried out prior to the commencement of mining and blasting operations at the Prestea North Pit.

4.4 Establishing Ground Vibration Threshold Level for Prestea Plant North Pit

With the information on the state of the buildings in the Prestea area, monitored ground vibration levels, blast design parameters and the corresponding vibrations they generated, the study set out to establish appropriate ground vibration thresholds for the mine to adopt.

For any blast to be considered safe and environmentally acceptable, the vibration levels generated should not exceed a threshold or maximum established level for the particular condition and location or country. A threshold level thus established could be adopted for use under other conditions provided appropriate corrections or adjustments are made, taking into consideration prevailing conditions in this new location. According to Persson *et al*, (1990) the correction or adjustment to this threshold value, V_0, may be obtained by applying such correction factors as construction quality factor, distance factor, project time factor, building factor and construction material factor, using equation (2) below:

$$V = V x F_k x F_d x F_t \qquad (2)$$

where V = Adjusted or corrected peak particle velocity (ppv), mm/s

F_k = Construction Quality Factor = F_b x F,,,

F_d = Distance Factor, (varies as to type of material on which the building is con structed and ranges, for example, be tween 0.22 for rock; 0.35 for moraine and 0.50 for clay materials for distances of over 350 m).

F_t = Project Time Factor (4.0, for stationary projects such as mines and quarries for which duration is one year or less and 0.75 for duration of 5 years or more).

F_b = Building Factor (=1.20 for industrial and office buildings, 1.0 for standard living buildings and 0.5 for buildings in dam ageable conditions and certain ruins).

F_m = Construction Material Factor (1.20 for reinforced concrete, steel and wood; 1.0 for not-reinforced concrete, brick or clinker, 0.75 for autoclave porous con crete and 0.65 for mexi-brick/artificial limestone brick).

In the absence of any local or national ground vibration thresholds, the authors adopted the German Standards and made suitable adjustments to suit the local conditions at Prestea and its environs. According to German Standards the maximum allowable level of ground vibration on a standard residential building should not exceed 8 mm/s (Persson et. Al. 1990). Considering the sub standard quality of buildings in the Prestea township and its environs, authors held the view that the German Standard of 8 mm/s was too high for direct application and therefore not acceptable. Appropriate adjustments were therefore made to this value using equation (2) together with the appropriate correction factors to obtain the value of 2 mm/s. This implies that the maximum ground vibration due to blasting activities at the pit that should be allowed on building structures at the Prestea township and its environs should not exceed 2 mm/s. Viewed against the results in Table 3 and confirmed by the results of monitoring where 4% of total blasts monitored had values in excess of the 2 mm/s, it can be seen that the blast design parameters being used at the pit at the time of this study were rather on the high side and could easily have caused some damage to buildings and structures. The adjusted blast design parameters are summarized in Table 4.

Table 4 Recommended Revised Blast Design Parameters

Type of Material	Oxide Ore	Transition Ore	Sulphide Ore
Bench height (m)	4	4	4
Burden & Spacing (m)	3 x 3	3 x 3	3x3
Sub drill (m)	0.5	0.5	0.5
Bottom charge (kg)	0.15	0.15	0.15
Column charge (kg)	14	14	14
Co-operating charge (kg)	14.15	14.15	14.15
Specific charge (kg/m^3	0.39	0.39	0.39
No. of Holes/Blast	100	100	100

The maximum vibration level expected from this blast design has been estimated as 1.7 mm/s. Further upward adjustments could be made to the explosive consumptions for improved fragmentation, if so desired, so long as the vibration levels do not exceed the recommended 2 mm/s.

5 Conclusions

It is imperative that in monitoring blast vibrations, frequencies at which the vibrations occurred must be indicated. Also records of weather conditions at the time of monitoring should be recorded.

Initial baseline studies are a good basis for comparative assessment of damage to building structures due to blasting operations in mining districts. Based on the quality and standard of most of the buildings in the Prestea township and its environs, maximum ground vibration level of 2 mm/s has been recommended.

Community interaction and education is crucial for the avoidance of misunderstandings and confrontation between mine management and the inhabitants in the adjoining settlements. The communities must be made aware that in mining there is generally a trade-off between benefits accruing from the operations and adverse losses to the affected communities.

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