# Blasting Standards for the Ghanaian Mining Industry

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## Abstract

Ghana is a well known mining nation and hard rock mining has been going on since the 10th century. Mining companies in Ghana are well aware of the regulatory requirements to carry out blasting activities such that neighbouring communities are protected from excessive impact as a result of blast vibrations amongst other known blast impacts. However in the absence local blasting standards in respect of ground vibrations companies are compelled to import standards from their country of origin or from some other sources. Communities continue to complain of cracks in their house as efforts by companies have not produced the desired results.

This paper studied the building types in the mining communities and determined threshold levels for ground vibrations based on crack monitoring activities carried out on some structures within the communities.

The results revealed that much lower ground vibration levels than those currently adopted were required to protect the type of structures prevalent in the mining communities. The paper makes some recommendation for best practice.

## 1 Introduction

Blast vibration standards have been established in most mining nations to regulate blasting activities so as to protect structures close to mining activities. Ghana is a well known mining country and hard rock mining has been going on since the 10th century. Most structures close to mining communities show several cracks which inhabitants attribute to vibrations arising from blasting activities. The basic construction material for houses in Ghana is earth or soil (Anon, 2007). The earth is used sometimes in the raw form without treatment or additives. For example the wattle and daub, atakpame and sun dried brick buildings. In some cases the earth material is stabilised by compression or compaction to increase their density and strength to produce compressed bricks or blocks, lancrete block and sand crete block for the construction of buildings The use of fire to improve strength is also employed in fire brick or block buildings.

In mining areas all these different types of buildings exist and are affected by blasting in different ways depending on their strength which is a function of their construction methods, environmental factors, material quality, age of building, distance and location from blast point.

Currently, there are about 70 companies with mineral rights for hard rock mining in Ghana and about 14 of them are operating close to settlements. However no vibration limits have been established to guide blasting operations at these mines.

This paper briefly outlines some basic information on the impact of seismic vibrations on structures and the method for determining permissible levels of ground vibration. The paper proceeds to present a study on the determination of threshold limit of ground vibrations for the Ghanaian mining environment.

## 2 Acceptable Threshold Levels Of Seismic Vibrations

The most widely accepted documentation on acceptable threshold levels of seismic vibrations (Anon, 2008a and b, Ollofson, 1990, Per-Anders Persson *et al.*, 1994) suggest that peak particle velocity (PPV) is the single best ground motion descriptor and the most practical method for regulating damage potential for a class of structures with well defined vibration response characteristics.

Homes eventually crack because of age and a number of environmental stresses, including humidity, settlement, temperature changes, hydrostatic soil pressures, wind and even water absorption from tree roots. Consequently, there may be no absolute minimum vibration damage threshold when the vibration from any source could in some cases precipitate a crack about to occur. Damage potentials for low-frequency blasts (<40 Hz.) are considerably higher than those for high frequency blasts (>40 Hz.), with the latter often produced by close-in construction and excavation blasts.

Assessment of the damage in structures should be made on the basis of measurement on the structures as such an approach is accurate and has substantial advantage because structure responses provide the flexibility of implicitly considering the variety of soil-structure interaction and structure conditions.

Guidance levels are used for establishing permitted vibration levels or threshold values for all types of blasting operations. Guidance levels are based on a broad well-documented correlation between PPV and induced damage to buildings founded on various types of geological formations (Oloffson, 1990). The Guidance level (V) is given by:

$$V = V_o F_k F_d F_t \qquad \text{equ.1}$$

Where,

- Vo = Uncorrected PPV
- Fk= Construction quality factor, and Fk = FbxFm,
  - Fb = Building factor, Fm = Construction material factor
- Fd = Distance factor, and for distances over 350m, Fd = 0.22 for rock, 0.35 for morain and 0.50 for clay
- Ft = Project time factor, (0.75-1.0), Ft = 1 for projects up to 1yr, and 0.75 for projects over 5yrs

The Construction Quality Factor Fk=FbxFm may be determined using Tables 1 and 2.

**Table 1 Building Factor Fb**

| Type of building or construction | Fb |
|---|---|
| Heavy Construction (Bridges, harbours etc.) | 1.70 |
| Industrial and office buildings | 1.20 |
| Standard living houses | 1.00 |
| Sensitive buildings (museums etc.) | 0.65 |
| Historical buildings in damaged conditions | 0.50 |

**Table 2 Construction Material Factor Fm**

| Type of construction material | Fm |
|---|---|
| Reinforced concrete, steel or wood | 1.20 |
| Not-reinforced concrete, brick or clinker | 1.00 |
| Autoclave porous concrete | 0.75 |
| Mexi-brick (artificial limestone brick) | 0.65 |

## 3 Data Collection

Data for the study was obtained from records available on blasting activities from 8 mining companies. Measurements were done for cracks in 3 communities around selected companies.

### 3.1 Blast Monitoring Data

Arrangements were made to collect existing blast monitoring data, as well as the operating standards being used at all mine sites visited, where available. The blast monitoring data collected included:

- PPV levels (3 to 5yrs);

- Monitoring positions/ Distances from blast;
- Meteorological conditions at the time of blast; and
- Co-oporating charges or charge per delay, for each of the blasts monitored.

### 3.2 Crack Monitoring of Selected Structures

In order to determine the actual impact of blasting on the structures at the mine sites, crack monitoring was carried out on selected structures at selected mine sites. The underlining concept for this exercise is that while cracks in buildings develop from various causes, blasting should be designed such that in the least, whatever the initiating cause of the crack, blasts do not exacerbate or extend existing cracks. The weakest buildings in the community were the target structures for this exercise – Wattle and daub or "Atakpame" buildings.

The instrument used for monitoring ground vibrations was the Vibratech Multiseis V mini seismographs, and for crack monitoring the Avongard Digital Calliper was used.

### 3.3 Structural Characterisation of Buildings Monitored

Four (4) different types of wattle and daub buildings were monitored for crack extension in some selected mine sites.

**Structure No.1:**

- Wattle and daub rendered with cement mortar
- No foundation
- Rafters made from rounded poles of diameters ranging from 500mm to 750mm
- Presence of wall plates
- Roofed with corrugated roofing sheets
- Spalling of mortar from foundation to plinth level probably due to seasonal wetting
- Age of structure-10 years

**Crack Description:** Near vertical crack extending from the peak of the gable to the foundation of the structure (Fig 1)

**Fig 1 Crack on a Wattle and Daub Building**

**Structure No.2**

- Wattle and daub rendered with cement mortar
- Un-rendered apron around the building
- Apron detached from building
- Roofed with corrugated roofing sheets
- Age of structure-8 years

**Crack Description**: Through vertical crack extending from window to apron

**Structure No.3**

- Wattle and daub rendered with cement mortar
- No foundation
- Rafters made from rounded poles of diameters ranging from 500mm to 750mm
- Presence of wall plates
- Roofed with corrugated roofing sheets
- Age of structure-8 years

**Crack Description:** Near vertical cracks extending from the window level to the foundation of the structure

**Structure No.4**

- Wattle and daub rendered with cement mortar
- Spalling of mortar from the walls of the structure
- Unrendered apron around the building
- No foundation
- Partly roofed with corrugated roofing sheet, weeds and palm branches
- Age of structure-4 years

**Crack Description:** Through vertical cracks extending from the foundation to the gabble

The set-up for the monitoring exercise is shown in Fig 2.

**Fig 2 Set-up for Monitoring of Crack, PPV and Airblast**

## 4 Data Analysis, Results and Discussions

### 4.1 Data Analysis

Data collected from the various mine sites were processed as follows:

- PPV monitoring data were subjected to statistical analysis to determine the ranges of values, means and standard deviations.

- Prevailing standards across the world were subjected to various correction factors based on local conditions prevailing on mine sites in Ghana.
- Measured PPV and crack monitoring data are to be used to establish levels at which no crack or no extension of crack beyond acceptable limits is expected for the weakest community structure at the mine sites.

### 4.2 Results and Discussions

**PPV Level**

The results obtained from various mines between 2002 and 2008 were pulled together and the ranges of values, means and standard deviations were obtained. The results are given in Table 3.

**Table 3 PPV Levels for Mines in the Ghana (2002 – 2008)**

| Parameter | Peak Particle Velocity (PPV) (mm/s) |
|---|---|
| No. of Samples | 8494 |
| Maximum | 25.08 |
| Minimum | 0.002 |
| Mean | 0.76 |
| Standard Deviation | 1.06 |
| Mean+Standard Deviation | **1.82** |

Table 3 shows that vibration levels as high as 25mm/s occur within the communities.

### 4.3 Localised PPV Threshold Values

Threshold values were determined for the Ghanaian condition using threshold values from selected countries with the help of equation 1:

Given the type of structures at various mine sites, guidance level factors were selected as follows:

- Fk = 0.42, for building and construction material such as wattle and daub with rammed earth floor and thatched roofing (Fb=0.65, and Fm=0.65)
- Fd = 0.5, for distance of 350m and more and for foundation other than rock (say clay)
- Ft = 0.75, for stationary projects such as mines and quarries for which duration is more than one year

The PPV levels obtained for the Ghanaian local conditions based on commonly known international standards from various countries are given in Table 4.

**Table 4 PPV levels of some Countries and the Ghanaian Equivalent**

| Country | Standard PPV (mm/s) | Localised PPV (mm/s) |
|---|---|---|
| USBM | 12 | 2 |
| Australia | 10 | 1.6 |
| Germany(Res.) | 8 | 1.3 |
| Hong Kong/Rule of Thump | 25 | 4 |

Range of localised values: 1.3 to 4 mm/s

**Crack Monitoring Results**

A total of 70 readings of crack monitoring data from various wattle and daub structures of ages between 4 and 10 years were obtained, and a graph of PPV against crack extension was drawn, and it is shown in Fig. 3.

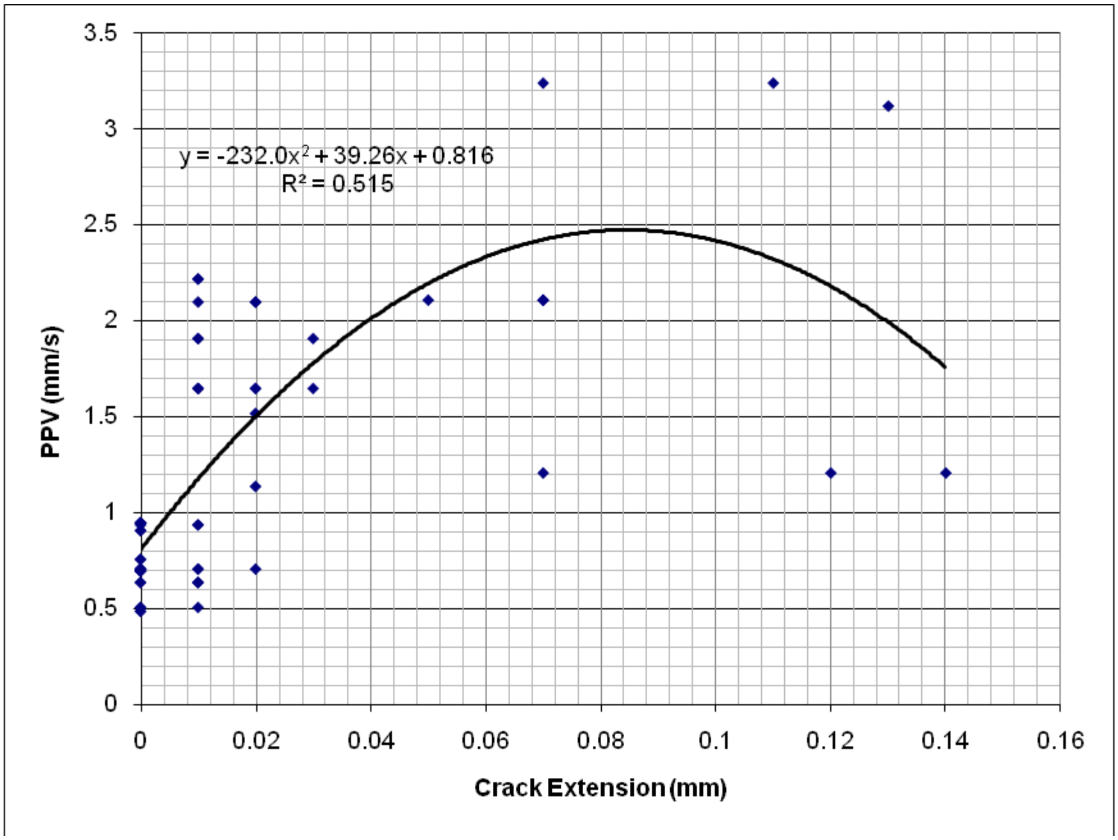


**Fig 3 Peak Particle Velocity and Crack Extension for Wattle and Daub Structures**

A critical look at the raw data obtained showed an elastic behaviour of the structures monitored. Crack extensions reduced sometime after the blast, though never to the extension measured immediately (up to 15minutes) after the blast.

The graph of PPV against crack extension, behaves like the stress-strain curve of a typical geo-material such as clay, silt or rock. Concrete also behaves similarly under load. The observed behavior is expected since the wattle and daub structures that were monitored are made of clay reinforced with wooden poles. The curve shows non-linear elastic behaviour with a maximum PPV. The following points can be defined on the curve:

**Zero Crack Extension:** This is the PPV that will not cause any extension in an existing crack. This means the blast vibration has no impact on the crack. On the graph the point at which the curve crosses the PPV axis is 0.8mm/s.

**Maximum PPV:** This is the PPV that a building crack can sustain under a given set of conditions such as temperature, wind etc. After this maximum PPV is exceeded, the crack undergoes loss of strength following little or no permanent deformation. This PPV is measured as 2.5mm/s.

Failure is said to occur at the maximum PPV or be initiated at the maximum PPV. Failure in this case is defined as the occurrence of permanent extensions in the crack due to weakening at the crack ends.

**Yield PPV:** This is defined as the PPV for which there is a departure from elastic behavior where some of the crack extension becomes irrecoverable. For the non-linear elastic behaviour, the yield PPV, like the yield stress, is usually very difficult to determine since the curve is not a straight line. Its determination is usually done by inspection of the curve combined with engineering intuition. By inspection, the yield PPV is determined as 1.6mm/s.

It may be noted that the data obtained from the mining companies revealed that various companies had adopted PPV thresholds values for internal use. The values ranged 1.5 to 6 mm/s. Only one company adopts 1.5mm/s while all other companies use values between 4 and 6mm/s.

Table 5 summarises the Peak Particle Velocities obtained from the mines, from adopted standards currently in use, from results using the guidance level concept, and from crack extension monitoring results.

From Table 5 an acceptable standard may be considered between the Maximum/Failure PPV of 2.5mm/s and the Yield PPV of 1.6mm/s. A PPV of 2mm/s is therefore a suitable value for the Ghanaian industry. This value is just about the same value as the mean value (plus standard deviation) obtained from the mines (Table 3) over a 5-year period (2004 to 2008).

Where most mining companies adopt between 4 and 6mm/s as their threshold, and where actual blast vibration levels could reach 25mm/s it is expected that wattle and daub structures will develop cracks and possibly failure could occur.

**Table 5: Summary of PPV Data**

| **Item** | **PPV mm/s** |
|---|---|
| Data from Mines | 1.82 |
| Adopted Standards in Use | 1.5 – 6 |
| Guidance Level Standards | 1.3 - 4 |
| Zero Crack Extension | 0.8 |
| Maximum/Failure PPV | 2.5 |
| Yield PPV | 1.6 |

## 5 Conclusions and Recommendations

Current PPV levels being adopted by most mining companies are above 2mm/s. It is hoped that if 2mm/s is adopted and strictly adhered to complains about cracks and other vibration impacts will reduce

It is important that more data on crack monitoring is acquired to validate the recommended 2mm/s peak particle velocity.

The standard recommended were established for wattle and daub structures, which are considered the weakest within the mining communities. Other structures at the mine sites include "atakpame", sundried brick or block buildings, compressed brick or block structures, landcrete block and sandcrete block structures. It is recommended that similar studies to include these structures be conducted.

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