Determination of Blast Vibrations Using Peak Particle Velocity at Bengal Quarry, in St Ann, Jamaica

Roy Fitzgerald Nicholson

Luleå University of Technology
MSc Programmes in Engineering
Department of Civil and Environmental Engineering
Division of Rock Engineering
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A case study

Roy Nicholson
Preface

It is my sincere hope that this master’s thesis is the first of a series of researches that will be used to develop standards for ground vibration caused by blasting activities. These researches should develop standards that are specific to Jamaica’s geological conditions. Although this paper was produced at the Lulea University of technology, Sweden, all field work and data collection were done at Bengal Quarry, St. Ann, Jamaica.

Throughout the two year period at LTU there are some rather influential and motivating people that I am extremely grateful to and wish to extend my gratitude. To Professor Erling Nordlund, and the entire division of Rock Mechanics and Mining Engineering family, all were extremely helpful and supportive. For this I am very truly grateful. To Daniel Johansson and his colleague Ulf Nyberg, I am thankful for the support and guidance throughout the preparation and presentation of this thesis.

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ABSTRACT

In recent times Jamaica has experienced an increase in infrastructure and mineral resource (bauxite) developments. As a result, quarrying activities have also increased to supply the needed construction material. Blasting has been the main technique for loosening in situ rock before transporting to construction site. Consequently there is a growing concern of the effects of blasting activities on the environment. These effects are normally nuisances to the neighbouring residence as they come in the form of: dust, toxic gases, noise, fly rocks and ground vibration. Of the set of nuisances the one that is of most concern is ground vibrations which can cause damage to structures. In most cases worldwide, after blasting activities there are the usual complaints about damage to residence, which is also a focus of the thesis.

There have been researches on the subject of ground vibrations to help refute some of these complaints. The works of Lewis Oriard and Charles Dowding are the foundation on which standards and regulations are built as guides to assist blasters in the prevention of creating unnecessary nuisances. Most countries have developed their own regulations with respect to blasting and parameters are set according to the geological conditions. This is of importance as the rock structures determine the transmission of the peak particle velocity. However, most countries in the west adopt standards similar to ones put forward by the United States Bureau of Mines or The Office of Surface Mining. It my opinion that a whole scale adoption should not take place as the criteria used may not be suitable for other countries’ geological conditions.

For this thesis the aim was to identify a vibration level that will not cause damage to structures close to a quarry. Based on the literature review it was revealed that there are a number of parameters that needed to be considered. These ranges: construction material, age of structures, distance from structures, geology of the location, type and quantities of explosives and the blast design. There was also the review of standards to building threshold with respect to the level of ground vibration.

The case study with its main focus on vibration levels at structures in close proximity to the Bengal quarry revealed that a tolerable level can be determined which will not
result in any form of damage to the structures. However, having established a PPV limit using the USBM and OSM standards that appears reasonable there is the need for criteria similar to those of the USBM and OSM using blasting and geological conditions in Jamaica. Due to the time constraints (20 wks) it is recommended that future research is carried out in this area especially in relation to assessing the performances of the structures.
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CHAPTER 1

Introduction

1.1

Background to Research

The use of explosives to execute blasting activities will always lead to concern as to its effects on the environment. Irrespective of the damage blasting might cause to the aquifers and underground water sources, not much attention are paid to such. However, the slightest of vibration felt by a householder can lead to major concerns and possible hefty law-suit on the blasting contractor or quarry operator. Many studies have been conducted worldwide to determine parameters with respect to ground vibrations that various structures can withstand without failure.

However, complaints are likely to follow after a blast even from homeowners who are well beyond a distance where structural damage can affect their property. These complaints are more than often fictitious and are strictly based on their perception, lack of knowledge and their observation to the structure preceding the blast. An experienced knowledgeable investigator of blasting effects on many occasions will dismiss this alleged damage on the following grounds. The alleged damage is not physically possible from vibration causes, it is too far away to be seriously considered and there is irrefutable evidence that the damage is old. The homeowner will likely remain adamant that the damage is from the blast due to the support that might be received by a consultant or contractors. Often times, these persons are not very knowledgeable of the relationship between waves and ground vibration. Their little knowledge has forced the homeowner to be very confident in consultant’s analysis of the situation even though it might not concur with damage caused by ground vibrations.

Being exposed to a number of situations where complaints are made of damage to structures after blasting activities, most of which are fictitious, has forced a desire to do some research in the area of effects of blast vibrations and structural damage. In this paper the focus will be based specifically on the Jamaican situation. There are
many researches that have been done and development of international standards with regards to ground vibration caused by blasting and possible damage to structure. However, looking at the geological conditions and the different building structures, it would be quite rewarding to determine some parameters specifically for Jamaica with the aid of the international standards and measuring of vibrations (peak particle velocity).

Currently, the United States Bureau of Mines standard for ground vibration (peak particle velocity) and damage threshold has been widely adapted in Jamaica. The intention of this research is not to remove this instrument but to use it as a guide to tailor made some parameters that are applicable to the conditions in Jamaica. These parameters should provide the blasters with information to design their blast in such a way that it will not cause any damage to the nearest structure irrespective of its integrity. The research paper will also provide the readers with adequate knowledge and better understanding of the ground vibration caused by blasting and its likely effects on structures at various distance from the blast sites.

1.2 Research Question

Over the past three years there have been increased blasting activities throughout Jamaica as a result of highway construction, haulage road in mining area or from regular limestone quarrying activities. Some of these activities have entered within or close to townships. Often times blasting is required due to the inability of mechanical machines to remove in-situ rocks. This method of blasting can be considered to be the quickest and cheapest if done with all the necessary precautions and best design. On the other hand if no special effort is in place for the employees’ safety and effects on the surrounding environment, then this method can be extremely expensive. [John F. Wiss. “Construction Vibrations: State-of-the-Art” Feb. 1981] The Kent County Council in The United Kingdom as the Minerals Planning Authority(MPA), has responsibility for preparing a Mineral Development Framework and dealing with planning applications for
mineral development, state the reason for blasting as: method that is only undertaken where geological conditions make alternative extraction techniques either impossible or uneconomical’ or where these alternatives would have worse environmental effects.

However, irrespective of the reason and purpose the blasting activities usually generate some level of annoyance to residents in the nearby population and possibilities of damage to the structures in the proximity. [Dr. Pradeep K. Singh, Blasting Department, Central Mining Research Institute, Jharkand] The annoyance from blasting stem from unused energy that was not sufficient to fracture the in-situ material further and lead to these unfavourable activities. These would include, noise, fumes, fly rocks, air and ground vibrations. These annoyances and nuisances usually result in the many complaints from the populates in the neighbouring areas.

Despite the efforts of the competent blaster to undergo the necessary precautions and design to ensure that the level of vibrations is within the international as stipulated by USBM there will still be complaints. According to the Mines and Geology Report in 2003 there were monitoring of blasting activities in some bauxite producing areas as well as along the newly constructed highway. This increased in activities resulted from the many complaints received by that office re damage to properties and structures from blasting activities. Since the vibration levels obtained in most of the activities are within the stated thresholds and complaints are increasing, this therefore prompts the questions for this research.

Can the parameters be determined for ground vibrations and air over pressure for maximum allowable PPV and tolerable noise level specifically for the Jamaican condition?

What will this parameter be with respect to the USBM international standards?

To answer these questions there will be no arbitrary altering of the USBM standards to derive at a figure but through careful collection and analysis of vibration data.
1.3

**Objectives of the Research**

The main objective of this thesis is to develop parameters that can be used as a guide for persons carrying out blasting activities at limestone quarries in Jamaica. It is also the intention of the writer to provide readers with some necessary and relevant information as to the link between vibration from blasting activities and damage to neighbouring structures. To develop a greater awareness and an appreciation in the readers that ground vibration induced by blasting does not always result in structural damage.

1.4

**Strategies to be Applied**

To achieve these objectives much work will be done through the collection and analysis of previous seismographic readings. There will also be the collection and analysis of new data in areas that are considered sensitive. In respect to sensitive areas it can be classified as area where homeowners continuously complain about blasting activities, areas with historical buildings as well as areas with buildings of questionable integrity. There will also be measurement from locations where structures meet the required standard of the building code.

The standard as stipulated by the USBM will be substantially consulted as a guide to develop these parameters. A requirement of say a PPV measurement of 20mm/s may be tolerable at a distance of fifty metres on an old building without causing any damage. It is therefore the idea to minimise this level so that there will not be any alarm by an individual due to there perception. Therefore, the seismograph will be extensively used to determine the levels of vibration at various distances. These will then be analysed and used to develop parameters to be used as guide for the blasters. It is also the hope that the Regulatory body with responsibilities for explosives and blasting activities in Jamaica will adapt some of these parameters and make them site specific for limestone quarries and at other sensitive blast sites.
1.5

Scope of the Research

It would be an enormous task to have a thorough research on all the factors and aspects that relate to structural damage as a result of vibrations induced by blasting activities. Much research has been done in order to develop international standards as to the stress level structures of varied materials and construction integrity may undergo without failure. With this in mind, the attention is on Jamaica with regards to its geological formation and the structural integrity of the buildings in that country. For this paper the focus will be on the vibrations and its effects on structures within threshold limits as recommended by the United States Bureau of Mines standard. This standard will be used to determine some parameters to be used as guidelines specifically for blasters in Jamaica.

Main concerns will be, to look at and measure the ground vibrations and air over pressure from blasts to set these parameters. One will not focus on the blast design or any other aspect of the blast activities that can lead to significant ground vibration. The idea behind this research is to use the peak particle velocity and air blast measurements from quarry and other blasting activity to determine PPV and Air Over Pressure limits at varied distances suitable for the Jamaican conditions.
CHAPTER 2

Blasting Environment

2.1

Introduction

In this chapter there is the review of explosives, some properties as well as some initiation system. Although each topic has not been focused on in depth the reader will have an understanding of the use and functions of explosives with regards to blasting activities.

Blasting is necessary for the recovery of ore in underground mines and many open pit mines and quarries operations. This aspect of the operation can be very effective not only in the mining and quarrying sector but also in the construction industry. Most times blast is applied in situations where the use of mechanical shovels is unable to remove the in-situ rock at a desirable rate. In this case blasting can be considered the cheapest and quickest way to shatter the rocks for easy removal. Blasting is also used as a means of increasing production in the mining and quarries sector. This process in the operations is considered very important. However, for optimization of this to yield the required outcome there are many parameters and sequences that must be followed. All these parameters will not be discussed in this paper due to the scope that is under investigation.

Despite the good intents of the mining, quarrying and construction operations to increase production with the use of blasting, they inevitable pose a source of nuisance to neighbouring communities. This normally results from noise, vibrations and flying rocks that can have significant impacts on lives and premises nearby. It is therefore necessary for the persons carrying out the blasting activities to exercise proper control over the blasting activities to eliminate any adverse effects on human beings or structures. This is necessary as the effects from each blast are not confined to the blast site and hence there is the need for guidelines as a means of protecting lives and properties.
The matter concerning guidelines will be discussed in later chapters but for the remainder of this chapter the focus will be on explosives, nuisance, safe handling and detonators.

2.1

Use of Explosives

In all major or minor activities where there is the need to remove in-situ rocks there is the application of blasting. This however, is to facilitate the easy removal of the material which has been fragmented. Blasting is a rather time consuming but expensive operation, it is used when conditions are not feasible for other excavation method. It might prove uneconomical to use the alternative methods or more environmentally disruptive than blasting. One of the major cost and component in blasting is the explosives. The type, quantity and quality of explosives help to determine the quality of the blast as well as the environmental effects.

The blasting process requires a number of drill holes at a calculated distance and interval (space and burden) as part of the blast design to yield the volume of material needed. The holes are then charged with explosives and a detonator, and then covered with stemming material. It is necessary to note that not all drill holes at all blast sites are charged the same way. Geological conditions as well as physical conditions help to determine the charge weight in each drill hole. Whenever, explosives are detonated in the blast holes under the confined conditions there are immediate changes in the constitutions of the explosives. In a very short time after the detonation there is the release of very high temperature and high-pressure gasses. The gases then expand at high force rapidly to overcome confining forces of the surrounding rock formation. This process will crush and fracture the surrounding rocks as the force exerted from the detonation of the explosive is greater than the strength of the surrounding rocks. After some distance from the detonated blast hole the force from the detonation is unable to carry out its destructive force as the rock strength is now greater than the exerted energy from the blast. It can be seen in the rock science term that the inelastic process ceases and elastic effect starts. “The excess explosive energy, not utilized in
shattering the rock is transferred to the elastic zone and thus propagates the disturbance away from the explosion site. This disturbance is known as shock wave or ground vibration” [Dr. Pradeep K Singh, et al, World of Mining, Volume 57/2005 No.1]

2.2

Types of Explosives used in Blasting

An explosive can be seen as a compound or mixture that can be ignited by heat, impact, friction or any combination of the three. When ignition takes place it decomposes rapidly to a state of detonation. When detonated, heat (4500 C) and large quantities of high-pressure gases (250,000bar) are released. The gases rapidly expand at extremely high forces to melt, crush and fracture the surrounding rock.

There are some technical properties of commercial explosives used that are necessary for the effective and optimal performance in a blast. The one that will be highlighted in this paper will be;

- Efficiency and stability
- Easy detonation and good explosive properties
- Safe handling
- Non-toxic
- Water resistance and good storage properties

2.3

Efficiency and Stability

The major characteristic in determining explosive efficiency in a blasting project is the Velocity of Detonation (VOD). This is the speed at which the detonation wave passes through the explosive charge. This is usually measured in meter-per-second. The velocity of detonation has classified commercial explosives into two categories which range from 1500 meters/second to approximately 7000 meters/second. All
explosives that fall between 1500 to 2500 m/s are classified as low explosives, while those above 2500 m/s to 7000 m/s are seen as high explosives. For production blasting only high explosives are used to facilitate the level of work the explosion must perform.

However, there are factors that will affect the velocity of detonation in a blast hole and prevent the full effects of the detonation. These factors are the type of product, diameter, confinement and the amount of priming. Explosives usually have a “critical diameter” which is enough to support the detonation process once it is initiated. If situations occur where the explosive is applied in diameter smaller than its “critical diameter”, then, the detonation process will not be supported and result in no detonation.

Sufficient priming is also necessary to provide the explosive with the boost needed to reach maximum velocity as quickly as possible. As stated before the quicker the detonation the more rapid the temperature and pressure gases will do their destruction on the surrounding rocks. Limiting the amount of priming material will lead to the reverse, where there will be slow velocity of detonation throughout the charged column. This will result in poor fracturing of surrounding rock formation and in some cases the charged column might not be completely detonated.

2.4

Easy Detonation and good Explosion

Most commercial explosives can be ignited by a blasting cap or an electric detonator. The explosives that are frequently used in production blasts require a primer of high velocity of detonation to start the process. Of the ANFO, slurry and most emulsion the one that is most likely to be ignited by an electric detonator is the ANFO. The slurry and the emulsion are considered to be high explosive and normally need a special design primer to start the initiation. Once the correct procedure was followed in the charging of the blast hole, as soon as initiation begins it is almost a certainty that the mentioned explosives will perform creditable.
2.5

**Safe Handling**

Manufacturers are doing their utmost best to ensure that explosives are safe for transportation and charging. The blaster should be at no risk when handling explosive. The danger should come about in the case of their negligence and not following proper blasting procedures. Sensitivity tests on commercial explosives, in terms of the stress, are carried out by allowing heavy objects to fall on the explosive from various heights. This will help to determine if impact from a rock on the explosive on the blast site will lead to detonation.

Sensitivity tests are also done to determine explosive reaction against friction. This is necessary as there might be the need to drill retrieving holes when there is a misfire in the blast (explosive not detonated during blast). In drilling this hole the drill bit might punch the explosive charge. If the explosive is very sensitive then it is possible to detonate if punched by the drill bit which can lead to loss of life and equipment. However, despite the insensitivity of modern explosive all effort should be made to prevent penetration of explosive with drill bits.

2.6

**Toxic Fumes**

Some blasts carry with it fumes that will be hazardous to health and the environment. The modern explosives are very much oxygen-balanced and are harmless. However, small amounts of toxic reaction products are formed as a result of deviations from oxygen balance, incomplete reaction or secondary reactions with the atmospheric air. “The amount of non-ideal detonation products depends on factors such as: composition and homogeneity; effect of water on the explosive after being loaded into a wet drill hole; velocity of detonation; charge diameter; loading density, in initiation type; cartridge wrapper and most importantly, explosive confinement. Before and
during detonation, additional reaction can also occur between the explosive and the surrounding rock such as when rock contains sulphide or other reactive components” [Quote taken from *Rock Excavation Handbook for Civil Engineering*, Tamrock]

From the many toxic gases that are formed only carbon monoxide and nitrogen oxide reach the level where it can be dangerous after a blast. However, there are threshold values stated for these fumes. The blasters should ensure that these are not exceeded. The inhalation of Carbon monoxide above the threshold level of 50ppm will lead to Asphyxiation. Nitrogen oxides are very irritating to the skin and the mucus membrane. When further oxidation takes places, nitrogen oxide becomes nitrogen dioxide. It becomes reddish-brown in colour and can be fatal if inhaled at a high concentration level. High levels of nitrogen dioxide contamination can be seen as anything above 30ppm.

Exposure to nitro-glycerine based explosives can lead to low blood pressure and headaches. The nitro-glycerine will dilate blood vessels which can lead to fatality if over exposed. This exposure can come in the form of contact with the skin during blast hole charging or inhalation of fumes after blast.

2.7

**Water Resistance and Storage Properties**

In some case in order to continue production in a quarry or open pit mine, charging will have to take place with substantial amount of water in the drill hole. The explosives that are used under these conditions should be water resistant as explosives being submerged under water for any extended period of time can lose its strength and become desensitised. Considering this phenomenon there is the production of plastic explosives that are high water resistant and the packagings of others are done with materials that are water resistant. It is necessary that in conditions where blast hole contains water an explosive that is highly water resistant is used. The use of ANFO is not recommended as the water is likely to desensitized such, and result in a failure of the proposed blast.
Most manufacturers of explosives usually, clearly label their products showing the shelf life of such. Despite the prolonged life of explosives it is highly recommended that these are used before these stamped dates. The life of these explosives can be shortened and lead to safety hazards, unreliability and underperformance with the storage facilities. Explosives are susceptible to either high temperatures or high humidity. In the storing of explosives one must ensure that the conditions regarding temperature are appropriate and surroundings are clean and dry. In terms of storage, this should not be for any long term but to facilitate earliest possible usage.

2.8  

Types of Explosives

There are quite a number of explosive with various grades to facilitate a specific blast site requirements. All these explosives have base of nitro-glycerine, ammonium nitrate, water or oil. Dependent on the base material each explosive is placed in a specific category:

- Nitro-glycerine based explosives ……. Classified as Dynamites or Gelatin
- Ammonium Nitrate based ………. ANFO
- Water based ………… Slurry
- Oil based ……….. Emulsion

2.8.1

Nitro-glycerine based Explosives

The effects on humans have seen a constant move away from nitro-glycerine in dynamites to ammonium nitrate. There are three types of dynamites: granular, gelatine and semi-gelatin dynamite. The latter two contain nitro cotton, a cellulose nitrate that combines with nitro-glycerine to form a cohesive gel. The granular type does not contain this nitro cotton stuff hence the texture is grainy.

These explosives are very water resistant and this comes about due to the quantity of nitro-glycerine that is used in the dynamite. They are excellent for bottom charge
especially in wet conditions or as a primer for blast holes with ammonium nitrate. When used as a column charge the percentage of nitro-glycerine is usually low. Due to the properties of dynamites they can be very effective in small diameter holes on construction sites. In certain pre-splitting and smooth blasting projects they can be effective but not recommended for large diameter holes production blast.

2.8.2

Ammonium Nitrate

This is a low cost, high power, extremely safe explosive made from porous prilled ammonium nitrate and fuel oil. The mixture of ANFO has a ratio of 94.3% ammonium nitrate to 5.7% fuel oil. The prilled ammonium nitrate acts as an oxidizer and the fuel oil as fuel. The velocity of detonation of this explosive is about 4500 meters/second and is categorized as a high level explosive.

Advantages of ANFO as an explosive

- Rather safe in the handling and use on blast sites because of its non-sensitivity
- Very cheap in comparison to other explosives. Approximately half the cost of nitro-glycerine explosives
- Produces better fragmentation of rocks on the muck pile due to its high gas producing properties. This makes it the blasted rock more manageable at the crushing plant.
- Among the best explosives for blasting in dry conditions with diameter holes more than 51 mm.

Disadvantages of ANFO as an explosive

- ANFO is not water resistance
- Does not detonate if wet
- Cannot leave ANFO in a loaded hole for any long period of time.
Cannot be detonated with a normal blasting cap or an electric detonator.

Often need a primer to start initiation

Should not be used with detonating cord in small diameter blast holes.

However, there are certain mixtures in which ANFO can be used in wet conditions. The mixture is ANFO with an emulsion explosive which is termed as Heavy ANFO. In heavy ANFO the prills act as voids or density adjuster and emulsion fill the gaps, the sensitivity, energy and water resistance is dependent on the level of each constituent.

2.8.3 Slurries

Slurries are water-based explosives that are water resistant, pumpable or applied in plastic bags. This explosive was designed for wet conditions and most applicable in large diameter blast holes. Despite a high Velocity of Detonation (VOD) between 3400 meters/second and 5500 metres per second such is not detonator sensitive. For initiation there must be the use of a primer along with the detonator. The contents of slurry are usually water, ammonium nitrate, aluminium and other substances to keep the explosive homo-geneous

2.8.4 Emulsions

Of all the commercial explosives the emulsion has the highest velocity of Detonation which is between 5000 to 6000 metres per second. This is advantageous as it produces high-shock energy which is a major factor in hard rock blasting. This explosive consists of a mixture of fuel and oxidant components. The oxidizers are nitrates and the fuels mostly mineral or hydrocarbon derivations. The ratio of oxidant to fuel is about 10:1 [Adapted from Rock Excavation Handbook, Tamrock]
2.8.5

*Advantages of Emulsion*

- Very high Velocity of Detonation (excellent for hard rock blasting as it provides greater energy at a faster rate)

- Cap sensitive for small and medium diameter blast holes

- Can be in bulk or cartridge form

- Can be mixed on site to provide continuous blast hole loading with precise amounts of various mixtures

- Can pump to speed of 200 kgs per minute.

- Water resistant

- Can remained uncharged for months under severe conditions

The many qualities, safe and versatile features have seen an increase in demand for this product. Its major attributes of being water resistance qualities and ability to stay uncharged for long periods then it becomes ideal for all conditions. It is likely to be the dominant explosive of the future.

2.9

*Initiation*

The initiation of explosives in a blast is very important as it often dictates the outcome of your blast. The use of electric detonators is an initiation system that is most frequently used. There are other non-electric methods that are used to initiate the explosive charge in blasting operations. The ones that are frequently used are:

- Firing chord and blasting cap
- Shock wave initiation
- Electronic detonator
2.9.1  
**Firing cord and blasting cap**

Safety fuse and blasting caps are adequate to fire single shot but prove inadequate in firing short delay charges as a result of the inaccurate burning rate. This method can start initiation of most explosives with a No. 6 cap but often times a No. 8 cap is used to provide that additional power for initiation. The safety fuse consists of black powder which is tightly wrapped in a water resistance coating. When this fuse is lit by a flame the black powder burns uniformly at a rate of 60cm per minute. The flame will ignite the blast cap which contains a small portion of high sensitive explosive then the igniting of the explosive.

2.9.2  
**Detonating Cord**

The detonating cord, like the safety fuse is a flexible tube that contains high velocity explosive that is cap sensitive. The core is usually protected with water proof material which makes it quite durable for most or all weather. This cord is not sensitive to ordinary shock or friction and robust enough to undergo minor severe treatment on the blast site without initiating.

The inner core of the cord is filled with PETN between 1 and 1300 grain per meter, the amount of PETN that is placed in the cord determines the grade of the cord. The most commonly used cord contains 80 to 160 grains per meter. The rate of detonation of this cord is between 6000 to 8000 meters per second.

Detonating cord is often used in large quarries and mines to detonate high explosives but is also effectively used in smooth blasting. It is normally used where there might be the presence of some external electricity that might cause unintended detonation an electric detonator. When this cord is used then there is the need for the safety fuse and the No.8 cap to start initiation.
2.9.3

*Electric Detonators*

The introduction of electric firing gave a higher degree of safety for the people involved in blasting operations.

The blaster is able to fire the blast from a protected area and could have the moment of firing completely under control. As it became possible to check with instruments that all the detonators were connected, the risk of misfires decreased.

The introduction of short delay blasting revolutionized the rock blasting technique, making it possible to overcome the problems with ground vibrations and increase the size of the rounds.

Electric detonators can be divided into three different classes due to their inherent timing properties:

- **Instantaneous detonators**
- **Milli-second detonators**
- **Half-second detonators**

The instantaneous detonator is a development of the plain detonator, where the safety fuse has been replaced by electric legwires and a fuse head which deflagrates and ignites the primary charge when the bridge wire receives an electric current.

Instantaneous detonators are used for stone and boulder blasting, presplitting etc., where no delay between the different charges is needed nor desired.

The Milli-second delay detonator has a built in millisecond delay element which delays the detonation a predetermined time. To be considered a millisecond delay detonator, the delay between each interval in the series should not exceed 100ms (0.1 sec). The Dyno Nobel millisecond delay series has 20 intervals with 25milliseconds between each. (see diagram 2.1)
The millisecond series may be prolonged with decisecond (100 ms) delays for tunnelling. Millisecond delay detonators are mainly used for bench and trench blasting.

The half-second delay detonator has a 500 ms (0.5 sec) delay between the intervals. It is intended exclusively for tunnel blasting where longer delays are required to prepare space for the movement of the blasted rock masses.

Electric detonators are in Europe divided into 4 groups based on the detonators’ inherent capacity to withstand extraneous electric hazards.
2.10 Hazards in electric initiation

There is no doubt that thunderstorms constitute the highest risk in rock blasting operations with electric initiation, due to its unpredictable nature and the high effects involved.

A stroke of lightning may have more than 1,000,000 V tension and as amperage of more than 100,000 A.

A direct stroke of lightning in the blasting area will initiate one or more detonators in the round, but even distant strokes is risky due to the extremely high amperage.

When a thunderstorm is closing in on a worksite, the site should be evacuated and all personnel must proceed to safe areas outside the risk zone.

Stray currents are quite common close to power stations in operation, and a Nonelectric initiation system should be used in such areas.

Electric welding equipment can cause stray currents and a safety distance of 30 m should be observed when such activities take place. Power lines may cause unintentional initiation by flashover, induced currents and through capacitive discharge.

The risks may be somewhat neutralized by:

- **Placing the firing cable on dry ground**
- **Avoid placing the firing cable parallel to the power line and in loops.**
- **Avoid that firing cable, connecting wires or leg wires are in conducting contract with earth.**
- **When extending the firing cable from the round to the firing point, the cable ends should be short-cut.**

When connecting to the blasting machine, the cable must be insulated from any conductive objects.
Close to power lines it is always risky to do blasting with electric detonators. The safety distances are different in different countries. In Sweden the following safety distances are recommended for different types of electric detonators (see table 1).

<table>
<thead>
<tr>
<th>Voltage kV</th>
<th>Group 1A detonators</th>
<th>Group 1A detonators</th>
<th>Group 2 detonators</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Legwires of iron</td>
<td>Legwires of copper</td>
<td></td>
</tr>
<tr>
<td>3-6</td>
<td>5</td>
<td>32</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>22</td>
<td>70</td>
<td>0</td>
</tr>
<tr>
<td>20-40</td>
<td>40</td>
<td>110</td>
<td>0</td>
</tr>
<tr>
<td>70</td>
<td>70</td>
<td>190</td>
<td>0</td>
</tr>
<tr>
<td>130</td>
<td>85</td>
<td>230</td>
<td>6</td>
</tr>
<tr>
<td>220</td>
<td>110</td>
<td>230</td>
<td>7</td>
</tr>
<tr>
<td>400</td>
<td>180</td>
<td>290</td>
<td>17</td>
</tr>
</tbody>
</table>

*Table 1 Safety distances for detonators*

Electric detonators may be initiated unintentionally by radio transmitters and radar. It is principally powerful middle wave and long wave transmitters that constitute a risk. For such transmitters a safety distance of up to 7000 m for Group 1 A and 2500m for Group 2 detonators are sometimes recommended. When blasting in the neighbourhood of radio transmitter it is wise to contact the owner of the transmitter and authorities to decide the safety distance.

Radar installations are often military and the authorities are reluctant to give information about the capacity of the installation and risks areas. So in the case of blasting close to radio transmitters and radar installations it may be better to select a non-electric shock tube system for initiation.
Portable walkie-talkie equipment and mobile radio transmitters can be used in the immediate vicinity of Group 1A, Group 2 and Group 3 detonators but a safety distance of at least 10 meters is the general rule for Group 1 detonators.

2.11

*Shock Tube Systems*

NONE is the original shock tube system that was introduced into the market by Nitro Nobel, Sweden in the beginning of the 1970’s. This is a non-electric initiation system. With the invention of NONE, blasters were provided with a worthwhile replacement for the electric detonator which has all the advantages of the electric detonator but none of its disadvantages.

NONE is not affected by any electric hazard and is seen as an ideal replacement in situations where electric firing is virtually impossible or not permitted by an agency for one reason or another. The NONE detonator functions similar to an electric delay detonator, but the leg wires and the fuse head have been replaced by a plastic tube through which a shock wave is transmitted. The end spit of the shock wave from the plastic tube initiates the delay element in the detonator.

The plastic tube, which has an outer diameter of 3 mm, is coated on the inside with a thin layer of reactive material. This transmits the shock wave with a velocity of approximately 2,000 meters per second. The plastic is unaffected by the shock wave and will consequently not initiate any explosives column it goes through.
CHAPTER 3

Environmental Concerns with Explosive (Blasting)

3.1

Introduction

In this chapter some attention is focused on some environmental concerns as a result of the use of explosives specifically in the area of blasting. There are nuisances that are likely to be present during and after every blasting activity. These effects are usually discomforting and at times dangerous to humans and their surroundings. The nuisances that are of most concern to humans are; fly rocks and vibrations, whether air or ground. Others such as, dust and gases emitted from the blast are of concern to individuals within close proximity to the blasting activities. Effects of gases emitted to the air from blasting activities were highlighted in an earlier chapter. However; for this chapter, it will specifically address fly rocks and vibrations with much emphasis on ground vibration. It will also highlight some standards and criteria under which to minimize some of these impacts as well as regulations to prevent structural damage.

3.2

Fly Rocks

Fly rocks are considered to be the most undesirable movement of rocks during the blasting activities. This type of concern although dangerous, is not as controversial as vibrations, as the immediate effects are visible. Damage by a fly rock cannot be refuted; the evidence is usually present and visible. An example is a case where a fly rock might go through a window; the rock will be there as well as the splinters, if not disturbed by individuals. This type of undesirable activity stems from a number of
factors and is easier to control than ground vibration and tends to be of a greater
comparison to the blaster than the neighbours.

The blaster makes the necessary calculations to determine a safe zone. This is usually
the maximum distance that a rock can be ejected from a blast hole and is calculated as
a function of the diameter. According to SVEBEFO Research the function is:

\[ L_{\text{max}} = 260 \left( \frac{d}{25} \right)^{\frac{2}{3}} \]

Where  \( L_{\text{max}} \) = Maximum throw in meters
\( d \) = diameter of blast hole,

Setting a reasonable safety zone is always a plus for the blaster to ensure that
undesired and unwanted accidents do not occur by ejected rocks from the blast.

It is necessary for the blaster to ensure that the blast is well designed and that all
calculations are done to facilitate specific conditions. Fly rocks can be a result of
overcharge, too small a burden, too large a burden or basic loose rocks on the crest of
the bench. Other factors influential to such behaviour in the blasting activity are:
delay times between adjacent holes, type of initiation, type of stemming and the
specific charge. Setting a reasonable safe zone and controlling fly rocks is of great
importance to the blaster as the penalties in these cases are usually more severe than
one with vibration problems. In some cases in the United States, blasters have their
permits to blast suspended, revoked and barred from using explosives for life.
Suspension usually accompanies retraining and hefty fines, while severe injury or
death from fly rocks lead to blasters being barred from blasting, fines and possible
imprisonment.
3.2.1

Preventing Fly Rocks

It is necessary to have a complete procedure and continuous follow up from the drilling of each blast hole. Given the profile of the drilled hole the blaster will be able to make the necessary calculations as to the charge weight per hole. The necessary, quantity and appropriate stemming can then be applied to ensure that the explosive in each hole is sufficiently compact for the effective use of the energy when detonated. Where fly rock is a problem in that specific geological area then the approach is to use explosives in a confined way. This will prevent the excess explosive in a drill hole as can happen in a free flow situation (use of truck or from sacks). Another way to ensure that there are no fly rocks is to apply a covering. This method often referred to as cover blast is quite effective when doing small blasts and is compulsory in populated area. Such a method however, is only applicable with small diameter holes (less than 3”) and hole depths that are less than twice the burden.

In cover blasting, the heavy covering (mat) is used to prevent any part of the blast to escape when the round is fired. At times a smaller mat is placed on the heavy mat, to prevent splintering of fly rocks to go airborne. The heavy coverings are approximately 3m x 4m in dimension and made from scrap tires banded together by steel wires. The light covering or splinter covering is constructed from industrial felt, mesh net or tarpaulin.

3.3

Air over Pressure

The term Air over Pressure is often used to describe airwaves that are generated by blasting activities. Lewis Oriard (1996) simply defines this as the pressure over and above that of the atmospheric pressure that is always present. This air over pressure
can also be described as air wave that passes through the atmosphere. Air waves are compressed waves that travel through the air. These waves travel in ways similar to that of compression waves that travel through the ground.

Although not impossible it is quite unusual for blasting activities to create air waves that will reach potential damaging level to buildings. If this should occur then the evidence is present and identifiable in the form of shattered or broken windows. Although this phenomenon might be rare much interest is attracted to air waves when they generate sound. The sound is what normally causes an alarm to residents especially if they are unaware of such activities. It is quite possible for air waves to generate audible sounds between 20 – 20,000 Hz which can be extremely annoying to humans.

3.3.1 Human Response

Human beings are able to hear sound at very low frequencies hence, there is likely to be a reaction at levels above their normal level. At times there are factors that cause the blast not to be as audible, these are: the depth of the charge, how low is the frequencies and how great a distance the person is from the blast. However, if a person is inside a structure, a loose door or rattling window pane can cause the individual to think exaggerated damage. The same person outside the structure will not pay much attention to the same air waves.

3.3.2 Air Pressure Criteria

Air over pressure is measured either in pound per square inch (PSI) or in decibels (dB) depending on which system you are using. The Bureau of Mines has done various observations and has made recommendations of certain criteria. For air over pressure it is at a level of 134 db that any minor damage structural damage is likely occur. Table 3.1 will give an overview of air over as it relates to structural damage.
Table 3.1 USBM Criteria for Air over Pressure

<table>
<thead>
<tr>
<th>TYPICAL AIR OVERPRESSURE CRITERIA</th>
<th>3.0 PSI (180dB)</th>
<th>possible structure damage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.0 PSI (171dB)</td>
<td>general window breakage</td>
</tr>
<tr>
<td></td>
<td>0.029 PSI (140dB)</td>
<td>long history of application as a safe project specification</td>
</tr>
<tr>
<td></td>
<td>0.0145 PSI (134db)</td>
<td>Bureau of mines recommendations following a study of large-scale surface mine blasting</td>
</tr>
</tbody>
</table>

It might be useful to note that the pressure limit 134 dB is equivalent to winds of about 28.5 MPH. Winds reaching ‘Gale’ force of 70MPH would be equivalent to air over pressure of 149.5 dB.

3.4

Ground Vibration

One of the most controversial issues facing the mining, quarrying and construction industry is ground vibration. There are quite a number of legal cases with these industries and citizens in close proximity to their operations, some issues at times are a bit fictitious while other stem from ignorance. Some of these complaints and alleged blast damage structures are exaggerated as a result of limited knowledge about the subject (Dowding1996). However these complaints and issues are likely to continue as mining companies are trending towards large blasts to maximize the use of large scale equipments. The problems of blast vibrations are therefore likely to escalate in and around residential areas. The onus is therefore on the blaster to design blasts in such a way to minimize ground vibration and maximize production.
3.4.1

The cause of Ground Vibrations

When an explosive charge is detonated in a rock, the charge is converted in hot gas and intense pressure. This pressure will melt and crush the rock around the blast hole to a certain point. Then there will be radial cracks until the rock loses its inelastic properties. Beyond the damage rock zone the pulse is called the elastic waves. No further permanent displacements of the rock particles will take place. The various seismic waves will be discussed in chapter four.

3.4.2

Peak Particle Velocity

As the seismic waves travel through the rock, there are movements of the particles. This is commonly referred to as vibration. The motion of the ground particles (vibration) occurs in three dimensions which are vertical, radial and transverse. When there is vibration each particle has a velocity and the maximum velocity is referred to as the peak particle velocity. This motion is usually captured by the use of a seismograph and the maximum velocities of all three directions are given. The practice by most is to use the reading of the peak particle velocity as the standard for measuring the intensity of the ground vibration. In reporting, the maximum measurement of any of the three components is used rather than the resultant vector of all three components combined. In most cases the PPV is closely linked to the potential to damage structures rather than the acceleration or displacement of the rock. A standard unit is used to measure this peak vibration, it is either inches per second or millimetres per second (1.0 isp = 25.4mm/s)
3.5

**Damage by Blasting Vibration**

Blasting vibration can only damage a structure if this vibration has exceeded the stress threshold of the structure integrity. It is quite unusual for this to happen considering the various numbers of researches that has done on various types of building material and structures of various ages to develop a standard. Should this happen the vibration will affect the weakest sections of the structure, at the window or at door jambs. Windows are normally made of glass which is unable to withstand the pressure of most building material hence, it is the most likely to be disturbed. The age of a structure and the construction material are factors that may result in damage from vibration. Despite the vibration below, the recommended threshold for such building and its physical condition may declare otherwise.

The different types of material in residential construction have lead to a considerable range of tolerance to vibration. Although 2.0in/s (50mm/s) is accepted as a safe limit by most authorities for quarry blasting, the average house seems to tolerate 20in/s (137mm/s) (Nicholls et al, 1971). Some years later research has proven that some residence will tolerate close to 20in/s (508mm/s) (Wiss and Nicholls, 1974). However, despite the range mentioned the geology of an area can contribute immensely to the propagation of waves that will lead to excess vibration levels. Distance between the structure and the blast site has an inverse relation with respect to vibration, as the further away you are from the blast the lesser the vibrations and vice versa.

3.6

**Vibration Regulations**

In most countries there are regulations and guidelines that are used to ensure that all vibration levels are kept within a specific limit. The United States have used the Office of Surface Mining (OSM) regulations and the United States Bureau of Mines
regulations (see figures 3.6.1 and 3.6.2) to determine their code and regulations, but may not be universally true. The geology of Jamaica is much different from that of the US hence a regulation for the US might not give the expected result. In such a case it is necessary to use the USBM criteria for reference to set conservative limits that will be most applicable for your area. An extremely conservative level is set at 1.0 in/s (25mm/s) for frequency above 40 Hz and 0.5 in/s (12.5mm/s) or less for low frequency vibrations is one of the regulations for quarry blast in the Jamaican situation.

The information collected from many years of research and field testing is the basis for the vibration limits set forth in order to minimize the damage due to blasting. The studies and field testing usually target the weakest material subjected to ground vibration. The material targeted by the USBM was plaster as is often the weakest material in construction. Many regulations, such as those established by USBM RI 8507, base their conservative ground vibration limits on the lowest level of threshold damage. Threshold damage as defined by the USBM includes the lengthening of pre-existing hairline cracks in plaster.

Currently, most ground vibration limits were linked only to peak particle velocities and authorities accepted 50mm/s (2.0in/s) as an acceptable safe limit for quarry and construction blasting. Crawford and Ward (1965) have indicated that these levels were very conservative and that most houses were able to withstand ground vibrations of approximately 137 mm/s (5.4 in/s) to 508mm/s (20in/s) before incurring minor
damage. This is by and large dependent on the construction material and the structure’s integrity.

The guidelines outlined by the Bureau of Mines in RI 8507, establish a correlation between frequency, particle velocity and damage limits. At lower frequencies, threshold damage limits occur at lower peak velocities. As the frequency of a wave increases, higher particle velocities are allowed before the damage limits are reached.

There are two main ways in which structures typically respond to ground vibrations. At higher frequency ranges, individual components of the house may vibrate. This movement is known as “midwall response.” At lower frequency ranges, the vibrations may cause movement of the entire structure. This is a result of the low natural frequency of oscillation of most building, commonly between 5-20 Hz. The deflection of the components with building is greater when the vibrations occur at the natural frequency of oscillation. As a result, the shear stresses are higher and there is a greater potential for damage when the ground vibrations at a structure are at low frequencies. The low frequencies may give the impression that the ground vibrations are worse than they actually are. L.L. Oriard stated however, that “Regardless of frequency, a vibration must reach certain intensity before it has any damage potential.” However, when possible it is more beneficial to avoid low frequency, long duration ground vibrations.

Vibration regulations are so developed to ensure that no damage is done to any structure irrespective of the type of construction material, age or its condition. This therefore forces the limitations to be more stringent than is necessary for most structures. From the Bureau of Mines recommendation guidelines as outlined in RI8507, such report establishes a link between threshold damage values and the frequency of vibration. The report recommends a limit of 50 mm/s (2.0in/s) for frequencies above 40 Hz. Limits of low frequency vibration are between 13 and 19mm/s (0.5 to 0.75 in/s) depending on the construction material. At a structure’s natural resonance frequency amplification factors ranged from 1.5 for the entire structure to 4 for the midwall. For frequencies above 40 Hz, all amplification factors for frame residential structures were less than unity. As a result, the threshold damage limits by most regulations are higher at higher frequencies. Therefore, in order to
minimize the possibility for damage due to ground vibrations, blasts should be
designed to produce higher frequencies. Therefore, local limits should be known
before beginning blasting. In Table 3.6.1 there is general outline of damage criteria to
residential structures with respect to ground vibrations (PPV). (Oriard, 2002)

Table 3.6.1  Range of Common Residential Criteria and Effects

<table>
<thead>
<tr>
<th>PPV (in/s)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.7 mm/s (0.5 in/s)</td>
<td>Bureau of Mines recommended guideline for plaster-on-lath construction near surface mines (long term, large scale, low frequency vibrations) (RI 8507)</td>
</tr>
<tr>
<td>19.1 mm/s (0.75 in/s)</td>
<td>Bureau of Mines recommended guideline for sheetrock construction near surface mines (RI 8507)</td>
</tr>
<tr>
<td>25.4 mm/s (1.0 in/s)</td>
<td>OSM regulatory limits for residences near surface mine operations at distances 92-1524 meters (301-5000 feet)</td>
</tr>
<tr>
<td>50.8 mm/s (2.0 in/s)</td>
<td>Widely accepted limit for residences near construction and quarry blasting (BuMin 656, RI 8507)</td>
</tr>
<tr>
<td>137 mm/s (5.4 in/s)</td>
<td>Minor damage to the average house subjected to quarry blasting vibrations (BuMin 656)</td>
</tr>
<tr>
<td>229 mm/s (9 in/s)</td>
<td>About 90% probability of minor damage from construction or quarry blasting. Structural damage to some houses depending on vibration source and character of the vibrations.</td>
</tr>
<tr>
<td>501 mm/s (20 in/s)</td>
<td>For close-in construction blasting, minor damage to nearly all houses and structural damages to some. For low-frequencies, major damage to most houses.</td>
</tr>
</tbody>
</table>

Other method of conformance as stipulated by the OSM regulatory limitations which in some part is adapted to the Jamaican situation is the ground vibration limits. In the case where a seismograph does not record frequencies the user of the explosive may use the peak particle velocities as shown in Table 3.6.2. The scaled distance is a ratio used for calculating peak particle velocity.
### Table 3.6.2 showing OSM ground vibration limits

<table>
<thead>
<tr>
<th>Distance (ft)</th>
<th>Scaled Distance</th>
<th>Peak Particle Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 300</td>
<td>50</td>
<td>1.25 (ips) 31.75 (mm/s)</td>
</tr>
<tr>
<td>301 to 5000</td>
<td>55</td>
<td>1.00 (ips) 25.4 (mm/s)</td>
</tr>
<tr>
<td>Over 5000</td>
<td>65</td>
<td>0.75 (ips) 19.05 (mm/s)</td>
</tr>
</tbody>
</table>

### 3.7

#### Some ways of Controlling Ground Vibrations

There are quite a number of factors that can either increase or decrease the intensity of ground vibrations. A number of these procedures to minimize fly rocks as stated previously are also applicable in the vibrations. However, the key and most critical factor for the blaster is to ensure that the blast is well designed for the geological conditions, rock, properties conditions and the availability of the explosives.

- Provide good control of drilling so that the spacing and burden from the plan are those that are achieved. In drilling ensure that a log of each hole is done so that the blaster will be prepared for any irregularities which might lead to overloading of a hole.

- Provide maximum relief commensurate with other factors so that there will be free movement of rocks with normal powder factor.

- Be aware of ground water as well as fractured zones and open seams. These are usually identified from the drill log.

If at all possible get information from the explosive suppliers as to the physical properties, performance characteristics and sensitivity of the explosive that will be used. This will help the correct choice of explosive for specific ground conditions especially if there are precautions and recommendations by the manufacturers.
CHAPTER 4

Ground Vibration, Waves and Monitoring Instruments

In this chapter the focus will be on ground vibration, air vibration and review of some international standards as regards to vibrations and structures. The standard that on will pay special attention to is the one put forward by the United States Bureau of Mines.

4.1

Introduction

In the modern society where there is the need for efficiency, high level of production and on time results the necessary strategies is needed to fulfil and achieve the required outcome. It the mining and construction sectors it is evident that there are very great demand for quantity, quality and efficiency hence the need to apply suitable methods to satisfy all interested parties. Despite the use of heavy-duty mechanical shovels they often need apply method with superior shattering powers especially when working with hard rock. The method that is most frequently used is blasting with the use of explosives.

The correct use of explosive will lead to extended life of equipment; make it less tedious and laborious to satisfy markets for minerals from mined ores and aggregates for the construction sectors. One must agree with Oriard (2002) where he stated that explosive not being an integral part of mining and construction the standard of living would be reverted as a result of other methods inability to fulfil the great demands by consumers.

However, despite the enormous benefits that might be derived from the use of explosives in the afore mentioned sectors, there are some negative and unwanted effects. These are usually present when procedures and protocols are not followed to ensure that maximum returns are received from the explosives used with very little or no negative impact outside the blast site. Negative effects from explosive use are
4.2 Ground Vibrations

In order to an understanding of ground vibration there is the need to have a synopsis of how explosive reacts to the ground when confined in a blast hole. When there is detonation of explosives in a confined space there are large build up of hot gases and intense pressure. The energy passes through the intact rock crushing it to approximately two times the diameter of the confined area. This is highly dependent on the type of rock as in some cases the cavity formed around the hole yields more than four times the volume. (Bauer, 1981)

Since the energy from the detonation is insufficient to crush further than four times the diameter of the confined hole, beyond that point radial cracks formed and extend the cavity. This energy continues to work on the rock by expanding these cracks. The lengths of these cracks are usually determined by rock properties, explosive properties and the blast design. The broken material will then move upwards and outwards, the level of movements depends on the strength and quantities of explosive. All crushing and cracking of the in-situ material take place within the inelastic zone. Beyond the Inelastic zone there is the elastic zone where no further permanent damage from the
explosion energy takes place. Oriard (1996) refers to the activities within the elastic zone as elastic waves; these may stretch and bend but will never break.

4.3

**Types of Waves Generated by the Blast**

When an explosive is detonated in borehole, energy is transferred into the surrounding rock as a result of the generated shock and gas pressures. Initially the pressure of the shock wave is higher than the compressive strength of the rock and the rock around the borehole is crushed. However the shock pressure decays quickly to values below the compressive strength. At this point the shock travels inside the rock without breaking it in compression. Failure of the rock is a result of tension through the tensile component of the shock wave or when the tensile wave is reflected as a tensile wave at media boundaries.

With further distance the shock waves attenuates into an elastic wave. In this case the stresses cause the particles of the rock to oscillate about their rest positions as a spring-mass system. There is no bulk movement or transport of matter during the wave motion.

The initial shock front applies a force to the rock in such a way as to compress it and reduce its volume causing a wave similar to a sound wave. Its characteristic is that it compresses and expands the rock by particle vibration in the direction of propagation. This wave type is termed compressional, dilatational, longitudinal or Primary and is usually designated by the letter P (P-wave).

Another type of wave which is produced by the initial pressure pulse and the later P-wave interacting with discontinuities in the rock is the S-wave. This type of wave is caused when the medium particles oscillate perpendicular to the propagation direction. Sometimes it is referred to as shear, transverse or secondary.

Introduction of one or more boundaries across which there are differences in elastic properties can cause the introduction of other types of waves. The most significant
boundary is the surface of the earth. Two basic surface waves exist. These waves are guided by the surface and are characterized by an exponential decrease in particle oscillation amplitude with increasing distance from the boundary and by the propagation of the wave from along the boundary.

The two fundamental types of surface waves are the Raleigh waves and the Love waves. The Raleigh wave causes surface particles to describe an elliptical counter clockwise orbit. These waves exist in the vertical radial plane and have no transverse component. The Love wave (Q-wave) is characterized by particle vibration of the shear type and only in the horizontal transverse direction. These waves are confined to a shallow surface zone.

![Diagram of wave types](image)

*Fig 4.3.1 Vibration waves from a cratering charge (Bauer 1981)*

Figure 4.3.1 shows the main wave types associated with blasting. These are produced by a hypothetical cratering charge. The P-waves are moving faster than the S-waves which are moving faster than the surface waves. The table (4.3.1) shows velocities of P and S waves in different rocks.
Table 4.3.1 Typical P and S Wave Velocities of Rocks

<table>
<thead>
<tr>
<th>Material</th>
<th>P Velocity, m/s</th>
<th>S Velocity, m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granite</td>
<td>4000-6000</td>
<td>2000-3000</td>
</tr>
<tr>
<td>Basalt</td>
<td>5500</td>
<td>3000</td>
</tr>
<tr>
<td>Sandstone</td>
<td>2000-3500</td>
<td>1000-2500</td>
</tr>
<tr>
<td>Limestone</td>
<td>3000-6000</td>
<td>2000-3000</td>
</tr>
<tr>
<td>Schist</td>
<td>4000-5000</td>
<td>2500-3000</td>
</tr>
<tr>
<td>Soil</td>
<td>150-1000</td>
<td>100-700</td>
</tr>
</tbody>
</table>

In general the S wave travels at a velocity of ½ to 1/3 of that of the P wave and the Raleigh wave at a velocity of 0.9 to 0.95 of that of the S wave (Oriard1996), (Bauer1981). At small distances all these waves arrive simultaneously while at greater distances they separate and identification is possible. However in mining most blasts consists of a series of explosions which are delayed by millisecond delays. This results in overlapping of the waves.

To describe the motions completely, three perpendicular components are necessary. The longitudinal which has the direction of a horizontal radius to the blast, the transverse which is perpendicular to the longitudinal on the horizontal plane and the vertical, which is perpendicular to both the longitudinal and the transverse. A typical vibration record is shown in Figure 4.3.2.

![Fig 4.3.2 showing vibration record.](image-url)
The advent of the seismograph put an end to the laborious task of doing complex mathematical equations to calculate or determine sinusoidal. The machines are so designed to give you all the necessary information from ground vibration, air vibration, frequencies or duration of the vibration. The figure 4.41 is a typical seismograph report for a seismograph station to record a blast. The instrument used was the Geosonic 550 2000DK built in the United States of America. There are different names of instruments from different countries but their main feature is to monitor the blast. See picture of the Blast Mate11 produced by Instantel out of Canada.
The seismograph recording the blast event will provide three different ground vibration readings on three channels. Each channel will represent an axis of particle movement. These axes that are recorded by the seismograph are: radial/longitudinal, vertical and transverse. The vertical axis is that which represents the vertical movement of the ground particles. The radial or longitudinal axis represents the ground movement that runs from the blast to the transducer at right angle to the radical channel.

For every blast, the seismograph will reassure the peak particle velocity of all three axes of vibration. For each of the peak particle velocity recorded there is a corresponding peak amplitude and frequency. As stated earlier in this paper, the particle vibration occurs in three dimensions: vertical, radial and transverse. When the
vibration occurs each particle is considered to have velocity and the peak particle velocity (PPV) is the maximum velocity of a ground particle in a given direction. Normally the vertical component is dominant over short distances so it is sufficient to measure vibration in the vertical direction. Since the seismograph gives the PPV of all three directions a current practice is to use the PPV as the standard by which the intensity of the ground vibration. The amplitudes as listed in the seismograph report particle velocity for each channel.

4.5

Conditions and Criteria for the Seismograph

To ensure that the readings from the seismograph are most accurate and not exaggerated then there are certain conditions and criteria to be taken into consideration. The USMB has done quite a lot of work on this and further readings can be done on the website. For this paper, a few of these, the writer thinks are most important are listed below.

1. Ensure that the geophones (transducer) are firmly anchored, whether by spiking or sandbagging.
2. Sensors should be placed within 3 meters of structure or less than 10% from distance of blast whichever is less.
3. The longitudinal channel should be pointing directly at the blast and bearings should be recorded by coordination.
4. The seismograph must be properly programmed, low enough to be triggered by blast vibration and high enough to minimize any occurrence of false event. A typical trigger level recommended by the USBM is 1.3mm/s

The writer wants to bring to your attention that these are not the only conditions and criteria to achieve accurate readings. There are papers put out by the USMB and other authors that will provide more in depth material on this subject.
4.7

Important Parameters

The important parameters of vibrations are peak amplitude, principal frequency and duration. The range of the typical parameters is shown in the table (4.7.1).

\[ \text{Table 4.7.1 Range of blast parameters.} \]

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement</td>
<td>0.0001 – 10mm</td>
</tr>
<tr>
<td>Particle Velocity</td>
<td>0.001 – 1000mm/s^2</td>
</tr>
<tr>
<td>Particle Acceleration</td>
<td>10 - 100000mm/s^2</td>
</tr>
<tr>
<td>Pulse Duration</td>
<td>0.5 – 3 sec</td>
</tr>
<tr>
<td>Wavelength</td>
<td>30 – 1500m</td>
</tr>
<tr>
<td>Frequency</td>
<td>0.5 – 200 Hz</td>
</tr>
<tr>
<td>Strain</td>
<td>0.003 – 5x10^3</td>
</tr>
</tbody>
</table>

The peak value does not always appear at the same time in the longitudinal transverse and vertical directions. For this purpose, the vector sum (resultant vector) of all components should be considered. However, most regulations refer to individual component.

4.8

Human Perception

Human beings are sensitive and can detect vibrations at very low levels although they are unable to determine the level that will cause damage to structures. Usually the rattle of a door or window by blasting activities will cause an alarm by the citizen as to structural damage. Often times, the slamming of a door or passing of a loaded lorry exert more vibration than a quarry blast. However, the rattling of objects in the immediate surroundings has forced the occupants to look for cracks to their residence. Finding this crack that was there before but not seen has lead to worry. Dowding (1996) sees this as human sensitivity being triggered by vibrations and air blasts that give rise to their enquiring minds. The idea that vibrations from a blasting activity reaching a residence result in some form of damage is therefore firmly entrenched.
CHAPTER 5
CASE STUDY ON BENGAL QUARRY

5.1

Introduction

It is the view of the reigning government of Jamaica to build a highway around the entire island. This view was materialized and construction started in the early 2000 for the westernmost point of the island towards the east via north. This project however has seen a greater demand for aggregate to be used as fill material for constructing road base and asphalt concrete. To acquire the higher production to facilitate the demand, heavy blasts are conducted in some of these limestone quarries. Some of these quarries are close to inhabited areas; hence the blasts will generate much annoyance to the residents nearby and possible damage to structures in nearby proximity.

As mentioned in previous chapters, rock blasting involves a series of phenomena; from the detonation process with explosives, the transfer from explosive energy from explosion products and action of the action of the energy on surrounding rocks. In a paper done by Dr. Pradeep K. Singh (2005) it is said that only approximately 15% of the total energy of is utilized for actual breakage and displacement of the mass while the remainder is spend on undesirable activities. These undesirable activities are ground vibration, fly rock, noise fumes and heat. Although some have been thoroughly discussed previously the one nuisance that is of most concern for this Chapter is ground vibration. Ground vibration is a major concern, as it can cause damage to surface structure and extreme annoyance to residents within the vicinity of where the quarry situated.

The Bengal Quarry also known as Jose Cartelone Quarry is situated in close proximity to an upscale north coast neighbourhood with the inhabitants having very sensitive equipments in their possession. This therefore leads to the decision to monitor and analyse impacts from the blasts conducted in the nearby village (200 m away).
The purpose of this study also was to establish some parameters and some form of criteria to suggest optimal blast design considering the safety of these structures and the equipment within. Findings also will be used as a background to set criteria for other quarries with similar geology and environment.

5.2

Description of Quarry Site

The Jose Cartelone Quarry is strategically located in terms of easy access and short haul distance to the company’s asphalt production plant. This limestone quarry is the main supplier of aggregate for asphalt, and roadbase for the construction of the Northern coastal highway segment 2. This quarry is located approximately 200m to the south of a village, 3 km to the west of a Marine lab and 1 km to the east of the Bay Vista resort.

The geology of the quarry is limestone of a coastal group which can be considered relatively young. This type of limestone consists of a sequence chalk and rubbly limestone. Such geological structure stipulates that the rock is not extremely hard, but for the needed volume blasting is necessary. For the first phase of the quarry the volume of material to be removed is 1,000,000 m\(^3\) with an option to increase perimeter for future quarrying. The layout of the quarry and the important structures in close proximity are in figure 5.2.1. In the figure structures are located within 200 and 400 metres radii of the quarry.

Figure 5.2.1 showing Jose Cartelone quarry with radii 200m and 400m
Surrounding Structures

The structures that were of much concern are those residences that were in close proximity to the quarry. Houses are closer than 200 meters to the quarry hence the need to be concerned about all possible nuisance from the activities in the quarry. All the structures in the village north of the quarry were constructed of reinforced concrete with steel. The buildings are relatively new and are well kept. If a construction factor is applied to the structures in the village more than ninety-five percent would score the maximum of 1.2. This is the highest construction factor for a residential building as calculated from the tables below.

Table 5.3.1  Showing values of building as a factor ($F_b$)

<table>
<thead>
<tr>
<th>Class</th>
<th>Type of construction</th>
<th>Building factor $F_b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Heavy construction such as bridges, defence buildings</td>
<td>1.70</td>
</tr>
<tr>
<td>2</td>
<td>Industrial and office buildings</td>
<td>1.20</td>
</tr>
<tr>
<td>3</td>
<td>Normal residential buildings</td>
<td>1.00</td>
</tr>
<tr>
<td>4</td>
<td>Particular vulnerable buildings and buildings with high vaults and spans such as churches and museums</td>
<td>0.65</td>
</tr>
<tr>
<td>5</td>
<td>Historical buildings in bad conditions and some vulnerable ruins</td>
<td>0.50</td>
</tr>
</tbody>
</table>

The following table shows the classes that building materials are divided with respect to the vulnerability to vibration. In calculating construction factor the weakest material factor ($F_m$) should be chosen.

Table 5.3.2  Numerical value for materials

<table>
<thead>
<tr>
<th>Class</th>
<th>Type of material</th>
<th>Material factor $F_m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Reinforced concrete, steel and timber</td>
<td>1.20</td>
</tr>
<tr>
<td>2</td>
<td>Plain concrete, bricks</td>
<td>1.00</td>
</tr>
<tr>
<td>3</td>
<td>Light weight concrete</td>
<td>0.75</td>
</tr>
<tr>
<td>4</td>
<td>Facades of lime-stones</td>
<td>0.65</td>
</tr>
</tbody>
</table>
The construction factor is the building factor multiplied by the material factor. The higher the value obtained is the more likely it is to withstand vibrations. With this in mind it is almost a certainty that theoretically the structure will withstand more than 50 mm/s.

In the figure 5.3.1 there is a photograph of the structures closest to the Bengal quarry. These locations were used as the monitoring stations during the collection of data for this paper. These structures are considered to be well maintained and have ages less than fifteen years. Most of the houses in this village are of similar vain.

Figure 5.3.1 showing houses closest to quarry (monitoring station)

5.4

Data Collection

Due to the sensitivity of the location of the quarry with respect to the houses and the Marine laboratory, a decision was taken by the Mines and Geology Division that all blasting activities must be monitored for vibration levels. The purpose of this form of regulation was part and parcel to help to prevent property damage as a result ground vibrations and air blasts from blasting activities. Seismographs are the instruments used to ensure compliance with the regulation put forward by the agency with authority for blasting activities in Jamaica.
To ensure that all the data collected was authentic the blasting company that is contracted by the quarry owner used the guidelines for monitoring ground vibration as stipulated by the International society of Explosive Engineers (ISEE). Adequate time was allowed for the setting up of the equipment. The person that was entrusted with the seismograph to collector the necessary data was quite verse with the equipment, its and manual its use. The instrument at no time was place closer than 1.3m away from the foundation of the closet structure with the microphone mounted about 1m above ground with adequate air muff to prevent pre mature trigger by high winds.

The trigger levels were set at 1.2 mm/s for the geophone and 120 decibels for the microphone. The location and distance from the quarry to the closest building was obtained by the aid of hand held GPS equipment.

The sensor was always adequately coupled to the ground and as level as is possible with the radial channel pointing directly at the blast site. All the necessary information with regards to explosive weight, atmosphere condition and any other information that will ensure a true reading were done.

Data for forty blasting events were collected for the use of this study. All the data collected were also capture on a floppy diskette which can be used at a later date if necessary. Some of the data collected are from the inception of the quarry in 2002, while some are as recent as August 2005. See appendix 1 for all data collected.

5.5

**Instrument used for Vibration Monitoring**

To collect all these data three seismographs were used at different time. At times when the conditions were considered to be serve at least two seismographs were used simultaneously. (Blastmate II and the Minimate). The Blastmate II and Minimate both of Instantel origin, have similar operation features to those of the Geosonic brand. They are all fitted with four channels, three channels for which, one triaxial transducers for monitoring vibration in the Longitudinally, Transverse and Vertical direction and one channel to monitor the air and sound.
5.6

**Citizens Response to Blast Vibration**

The blasting contractor with his knowledge did a thorough preblast survey of all the structures in close proximity. Despite doing this it was evident that there would be some complaints. Considering that this was a new phenomenon in this area the mildest of vibration will trigger an alarm. Considering where the person is at the time of the blast (indoors or outside) will help in determining whether he or she complains or not. Dr. Pradeep K. Singh (2005) also stated that no level is tolerable to everyone and complaints likely to follow most blasting activities whether fictitious or otherwise.

Following the completion of the first two blasts there were complaints of structural damage from the owner of the house closest to the quarry. The vibration levels were very low at that location and could not have caused any structural damage. The preblast survey showed the alleged damage complained about, the home owner was satisfied but not convinced.

However, for the first twenty five blasts there were complaints, from vibrations to dusting from the quarry.

This situation leads to the intervention of Mines and Geology Division, *(Agency in charge of all blasting mining and quarry activities)* which convene meeting with all parties to work out amicable solutions. It was ironic that after a number of meetings there were hardly any complaints with respect to the blasting vibrations. There were a few complaints about noise and even to recently there were still complaints about the unexpected noise.

It is possible for one to determine a conclusion about the scenario. At one extreme there are those people receive some tangible benefit from an operation and probably will not be disturbed by any level of vibration as long as it doesn’t damage their property. At the other extreme these are people who would be disturbed even by barely detectable vibrations.
Nemann-Delius (2002) concluded from extensive studies on the response of human beings to blast vibrations that people react to vibration well below the threshold limit.

5.6

**Presentation and Analysis of Data**

The data was collected and then placed in a table format *(see table 4.6.1)*. This will ensure that the readers will have easy access to the information. In the table, the highest peak particle velocity has been recorded. In reporting a common practice is to use the maximum peak velocity of any of the components rather than the sum of all three components. In this paper and like most others, the reading of the peak particle velocity is used as a standard for measuring the intensity of ground vibration. In most cases when reporting. However, if there is the need for information with respect to the resultant peak particle velocities, then such can be obtained from appendix 1.
Table 5.6.1 showing data from seismograph report

<table>
<thead>
<tr>
<th>Reported Exp/ Delay (kgs)</th>
<th>Distance Reported (meters)</th>
<th>PPV Reported mm/s</th>
<th>Frequency Reported (Hz)</th>
<th>PPV in/s</th>
<th>Air Pressure Reported (dB)</th>
<th>Scaled Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>220</td>
<td>4.8</td>
<td>14.7</td>
<td>0.19</td>
<td>123</td>
<td>73</td>
</tr>
<tr>
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<td>18.5</td>
<td>0.12</td>
<td>120</td>
<td>78</td>
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<tr>
<td>36</td>
<td>270</td>
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<td>166</td>
<td>0.08</td>
<td>100</td>
<td>110</td>
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<tr>
<td>18</td>
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<td>No events above 1.2mm/sec</td>
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<td>0.1</td>
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<td>1.5</td>
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<td>154</td>
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<tr>
<td>43</td>
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<td>31</td>
<td>0.25</td>
<td>124</td>
<td>118</td>
</tr>
<tr>
<td>27</td>
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<td>0.45</td>
<td>121</td>
<td>85</td>
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<td>0.005</td>
<td>127</td>
<td>87</td>
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<td>0.09</td>
<td>125</td>
<td>76</td>
</tr>
<tr>
<td>22.8</td>
<td>213</td>
<td>0.76</td>
<td>07</td>
<td>0.05</td>
<td>115</td>
<td>99</td>
</tr>
<tr>
<td>22.7</td>
<td>162</td>
<td>0.49</td>
<td>07</td>
<td>0.02</td>
<td>118</td>
<td>76</td>
</tr>
<tr>
<td>18.5</td>
<td>133</td>
<td>0.13</td>
<td>N/A</td>
<td>0.005</td>
<td>120</td>
<td>69</td>
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<tr>
<td>25.4</td>
<td>244</td>
<td>1.65</td>
<td>07</td>
<td>0.06</td>
<td>129</td>
<td>108</td>
</tr>
<tr>
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<td>0.005</td>
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<td>112</td>
</tr>
<tr>
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<td>0.002</td>
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<tr>
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<td>0.01</td>
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<td>22.7</td>
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<td>0.67</td>
<td>06</td>
<td>0.03</td>
<td>120</td>
<td>85</td>
</tr>
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<td>195</td>
<td>2.92</td>
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<td>0.11</td>
<td>123</td>
<td>91</td>
</tr>
<tr>
<td>17.3</td>
<td>162</td>
<td>2.03</td>
<td>11</td>
<td>0.08</td>
<td>125</td>
<td>87</td>
</tr>
<tr>
<td>45</td>
<td>276</td>
<td>1.27</td>
<td>06</td>
<td>0.05</td>
<td>132</td>
<td>91</td>
</tr>
<tr>
<td>45</td>
<td>425</td>
<td>0.13</td>
<td>47</td>
<td>0.005</td>
<td>116</td>
<td>140</td>
</tr>
<tr>
<td>18.8</td>
<td>122</td>
<td>0.13</td>
<td>N/A</td>
<td>0.005</td>
<td>120</td>
<td>63</td>
</tr>
<tr>
<td>23.2</td>
<td>244</td>
<td>0.59</td>
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<td>0.02</td>
<td>111</td>
<td>112</td>
</tr>
<tr>
<td>28.3</td>
<td>244</td>
<td>0.89</td>
<td>08</td>
<td>0.04</td>
<td>126</td>
<td>101.4</td>
</tr>
<tr>
<td>24.2</td>
<td>183</td>
<td>No events above 1.2mm/sec</td>
<td>No events above 1.2mm/sec</td>
<td>No events above 1.2mm/sec</td>
<td>No events above 1.2mm/sec</td>
<td>No events above 1.2mm/sec</td>
</tr>
<tr>
<td>24.2</td>
<td>213</td>
<td>No events above 1.2mm/sec</td>
<td>No events above 1.2mm/sec</td>
<td>No events above 1.2mm/sec</td>
<td>No events above 1.2mm/sec</td>
<td>No events above 1.2mm/sec</td>
</tr>
<tr>
<td>16.5</td>
<td>186</td>
<td>0.25</td>
<td>N/A</td>
<td>0.09</td>
<td>118</td>
<td>101</td>
</tr>
<tr>
<td>13</td>
<td>252</td>
<td>0.16</td>
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<td>0.007</td>
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<td>154</td>
</tr>
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<td>22.7</td>
<td>230</td>
<td>0.67</td>
<td>06</td>
<td>0.03</td>
<td>120</td>
<td>107</td>
</tr>
<tr>
<td>23.6</td>
<td>250</td>
<td>0.22</td>
<td>05</td>
<td>0.009</td>
<td>118</td>
<td>114</td>
</tr>
</tbody>
</table>

From the table a scattered plot was constructed to compare the scaled distance with the reported peak particle velocity. This was done to determine whether any point has fallen outside the reference line as recommended by the USBM standards. Such information is clearly outlined in figure 5.6.1
Fig 5.6.1 Scattered plot scaled distance versus particle velocity (USBM)

From the scattered plot it was evident that all the ppv values are below the national maximum level as prepared by the USBM. Most of the values fall below the mean value which is considered to be good for this situation. The vibration was almost negligible in some cases and could not be placed on the plot, while on a few occasions there were trigger from the instrument.

Figure 5.6.2 Diagram showing data as against USBM criteria
5.7

Results

The data collected for the thirty four blasting activities have shown that the PPV was not sufficient to cause any structural damage according to the standards put forward by the USBM. The PPV ranges from a low of 0.06 mm/s to a high of 11.5 mm/s which revealed that the vibration intensities were not at unbearable levels. In comparing such range with other standards it is unlikely for such vibration to cause any structural damage to the buildings in close proximity to the quarry.

The vertical waves recorded the highest PPV value at maximum at a level of 11.5 mm/s which is well below the 50 mm/s recommended by the USBM standards. It was also noticeable that on few occasions the instruments did not trigger at the level set, as the vibration levels from the blasts were not enough to cause such.

The sound level (air/pressure) ranges between 100 dB and 135 dB. From the forty monitored blasts there were seven occasions where the levels were above 120 dB. It is quite likely that it was on the days when the air over pressure exceeded the 120 dB that the citizens were complaining about the noise. Checks with the Mines and Geology division have revealed that the days when the air over pressure level recorded 135 dB there were many complaints of noise. There were even complaints about rattling of doors, windows and other loose articles in homes closest to the blast sites.

The vibrations were monitored in terms of the peak particle velocity and from data collected it varied from a low of 0.06 to 11.5 mm/s. These were dependent on the amount of explosive detonated per delay, the distance from the blast face the set up of the monitoring instrument on the particular day. The highest level of vibration recorded was 11.5 mm/s at a distance of 200 metres from the blast face. This 11.5 mm/s PPV lasted for approximately 0.75 of a second. Although this level of vibration is tolerable for reinforced concrete structures there is some concern. The reported quantity of explosives per delay was twenty-seven kilograms (27 kg), one will want to attribute the high vibration level to possible cooperating of charges or improper coupling of transducers with ground.
All the other PPV levels measured fall somewhere between 0.06 and 4.8mm/s. It is possible for vibration from traffic to exceed some of the PPV recorded. The main thoroughfare is merely fifty metres (50m) away from the nearest house; hence there is the possibility for the generation of vibrations of greater magnitude than those of the blast.

The maximum air over pressure recorded was 135dB at a distance of 252m with maximum weight of thirteen kilograms (13kg) per delay. The initiation system used for this specific blast was the conventional cord. This was used as a substitute for the NONEL system on that day due to the overcast conditions, the threat of thunderstorms and the unavailability of the shock tubes at that time. It is noted from the data that all the other measurements fluctuate between 100 and 127 decibels. Three blasts were done with the Nonel initiation system at various distances to the residence in the village. From this study a possible conclusion is that the Nonel system is likely to generate or reduce the air over pressure.

A Scale Distance SD =55 for distance between 301 ft (92m) and 5000ft (1515m) is considered to be conservative. In order to calculate the amount of explosive needed per delay to limit vibration intensity the formula $SD = D/Q^{1/2}$ can be applied.

Where $D$ is actual distance from blast and $Q$ is the maximum weight of explosive per delay

In applying some mathematical rearrangements to such formulae the weight can be determined by $Q = (D/Q)^2$

In the case of the Jose Cartellone Quarry, with the nearest residential structure being 200m (660ft) away, the maximum quantity of explosive needed per delay would be

$$\text{Weight per delay} = (660/55)^2 = 142 \text{ lbs} \quad 1m = 3.3\text{ft}$$
$$= 64.5 \text{ kg} \quad 1kg = 2.2\text{lbs}$$

Since for the immediate operations of the quarry were confined to distance less than 1500m the chosen scale distance equation was the most appropriate to use.
The data has revealed that no more than 45kg of explosive per delay was detonated. The above computation revealed that a maximum 64.5kg per delay can be fired in a blast with respect to the safety of the structures in close proximity. Therefore houses in the village of distance 200m or more will not suffer any vibration of great intensity that could lead to any form of structural damage as maximum PPV with 64.5 kg would be 25.4mm/s.

In using an equation to determine peak particle velocity, the one stated by the OSM version is applied,

$$PPV = 438 \ (SD)^{-1.52}$$

An average of 27kg per delay that was used in the quarry gives a threshold value for a distance of 200m to be 12.8mm/s. This is calculated as

$$PPV = 438 \ (SD)^{-1.52}$$
$$= 438 \ (200/\sqrt{27})^{-1.52}$$
$$= 12.5mm/s$$

The dominant peak frequencies of the vibration recorded rank in the range from 5 to 36 HZ. A threshold value of 25.4 mm/s can be considered for a safe blast design. Although this maximum weight of 64kg per delay can be used in a design there will be no damage to the house. To be as conservative as is possible it would be reasonable to design a blast that will not exceed PPV of 12.5 mm/s.
CHAPTER 6

Recommendations and Conclusion

6.1

Recommendations

In undertaking the task of doing this paper, it has revealed that most practicing blasters rarely follow guidelines. It is the duty of the authority in charge or the regulatory body in charge to provide the necessary conditions and limitations to be adhered to. These limitations should not only be prepared but should also be enforced.

In Jamaica it is the duty of the Mines and Geology Division to produce and provide the necessary limitations for users of explosives. Considering that the geology of Jamaica is somewhat different from the United States then the OSM and USBM limitations should not be followed laboriously. There should be some level of research carried out with the OSM and USBM limitations as a guide. For example, the distance that is applicable for Sweden is not applicable for the United States. It is therefore my opinion that the sealed distance applicable in the United States may not be extremely suitable for the Jamaican condition. Although it is currently used, one must be cognizant of the fact that the rock properties of the two countries are different.

The onus is therefore on the authorities in Jamaica to ensure that the practicing blasters are provided with the necessary and recent information. The limited facilities available and access for further development of users of explosives put them at a disadvantage. It is therefore the responsibility of the Mines and Geology Division to provide the necessary training, seminars and workshops for all these users who are lacking in these areas.
In general all users of explosives should ensure that there are aware of guidelines and limitations for a specific area. It is quite unlikely that any two locations have identical geology and rock properties. Therefore the blast that was designed for a quarry twenty kilometres away might not be applicable elsewhere. It is therefore necessary that before the user of the explosives makes the design he should have prior knowledge of the geology of the area.

As stated previously, one of the major nuisances to human beings from blasting activities is ground vibrations. Residents are at times more concerned about their property than health. The slightest of vibration will lead to complaints related to property damage. The blaster must ensure that all precautions are taken to minimize this vibration problem.

Residents rarely have any close observation and inspection to their property. As soon as there is a blast and any vibration is felt, then all the cracks are now visible. To try and alleviate the many complaints that might occur an in depth preblast inspection of the property must be carried out. In doing this preblast inspection clear documentation of all the visible cracks or any observed damaged to the structure must be made.

In doing this the blaster will have this document to refute any alleged complaints of damage for blasting activities. Should there be a complaint the blaster may also apply the strategy of setting up a seismograph at the complainant’s home on his next blast. Using such a strategy along with the preblast document the blaster may be able to convince the complainant that the property was not damaged by blasting activities.

When using a seismograph to monitor the vibration or air pressure there are guidelines that must be followed. In following these guidelines it is quite likely that a correct and authentic reading will result. Aspects such as the proper coupling of transducers, the correct information typed into the machine and the correctly set trigger levels are all necessary for accurate readings. In the reading of a seismograph, it is important to note the frequency of each wave. Waves with low vibrations usually travel far distance and can cause annoyance at distance where the PPV is very low.
These are not the only criteria that are necessary for the correct use of the seismograph. More detailed information can be obtained from the USBM website. It is also necessary to note that not all seismographs are programmed in the same way. The user must have a good knowledge of how the specific monitoring machine functions.

The type of explosives and/or initiation system in a blast can influence the air pressure and ground vibration. It is therefore necessary to have the specification by the manufacturer as to his product. This may stem from shelf life to its sensitivity. With regards to the Nobel shock tube air over pressure system is recommended over the traditional detonating cord. It is likely to reduce the level of air over pressure. This Nonel system is also a reputable substitute for the electric initiation system. It will do the work of the electric detonators but are not vulnerable to the many electric hazards.

The blaster should ensure that he has a well designed blast. In doing so all precautions must be taken into consideration. The entire blasting activity should be a process starting from the drilling of the holes. A thorough record of each hole must be available for the proper loading of each hole to prevent over loading of the explosives. Use the appropriate explosives and initiation system that will foster maximum use of energy and limited amount of nuisance.

Finally it is necessary for all users to be familiar with the latest technology in the use of explosives. They should aware of international limitations and criteria and be knowledgeable about those that are stipulated for your area. This is likely to provide you with the necessary knowledge to produce better blasts with limited nuisances.

6.2

Conclusion

The blast vibrations generated and propagated at the Jose Cartellone Quarry in St. Ann, Jamaica were too low to cause damage to the structures in the nearby village. The Maximum Vertical Peak Particle Velocity of 11.5mm/s was recorded near the foundation of the nearest house. All the blasts recorded fall well within the safe limit.
There is also a similar situation for the air over pressure as the highest value of 135dB was within a tolerable range. It is likely though that, citizens within their residences could be alarmed as to possible damage to property due to perception at 11.5mm/s. A similar situation could also occur with the air blast reaching a high of 135dB.

Using the Nonel initiation system is likely to reduce air over pressure if compared with the conventional detonating cord, although from the data all the air over pressure fall within a safe limit.

The analysis of the data has lead to the conclusion that the quarry can be expanded in a southerly direction. The quantity of explosive per delay should not exceed 45kg per delay which should result in a vibration peak particle velocity of 18.6mm/s. The frequencies should not fall below 12 Hz as low frequencies tends to result in possible longer vibration periods. These levels can be considered very conservative due to the sensitive nature of the inhabitants in the vicinity of the quarry.

In conclusion, it was not possible to cover all the aspects that contribute to ground vibration. It is the hope of the writer that the readers will have a better understanding of ground vibration from blast and its effects on structures.

From the case study the limit set for the quarry was determined merely on the peak particle velocities. All the reported values were below the threshold as stated by USBM and could not cause any structural damage. The air over pressure level was also within range and can be considered satisfactory. The only possible result that is likely to stem from the levels recorded is annoyance. This would be as a result of air pressure (noise).

Although tolerable levels have been determined for the quarry it must be noted that these parameters are site specific. They are applicable for the Jose Cartellone Quarry but may not be for other quarries. Further work must be done in order to create standards for Jamaica. However it is possible to extrapolate from such when blasting in areas with similar conditions as a guide to blasters to keep ground vibrations within a required standard.
Seeing that a standard for PPV limits can be established and appears to be reasonable when compared to the OSM and USBM standards, it is now necessary to develop standards similar to those specifically considering the Jamaican geology and blasting conditions. Therefore, for future research work must be done on assessing the performances of the structures with regards to vibrations.
References


Bauer, A. (1980), “Course Notes”, Department of Mining Engineering, Queen’s University, USA.


World Mining Magazine, (57/2005) no.1 pp. 53-58

www.min-con.com
www.blastecservices.com
www.isse.com
www.tec-eng.on.ca
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Appendix 2

Typical blast vibrations can be approximated as sinusoidal. Therefore, the equation for displacement can be written as

\[ d = D \sin(kx + \omega t) \] (EQ1)

Where \( d \) is the displacement
- \( D \) is the maximum displacement
- \( k \) is the wave number
- \( \omega \) is the circular natural frequency
- \( t \) is the time
- \( x \) is the distance

The constant \( \omega \) can be expressed as

\[ \omega = 2\pi \left( \frac{1}{T} \right) \] (EQ2)

Or

\[ \omega = 2\pi f \] (EQ3)

Where \( T \) is the period of the wave and
- \( f \) is the frequency.

Furthermore it is

\[ T = \frac{\lambda}{C} \] (EQ 4)

where \( \lambda \) is the wave length
- \( C \) is the speed of the wave

From equation (1) after differentiation the particle velocity \( d' \) and the particle acceleration \( d'' \) can be found. It is

\[ d' = D\omega \cos(kx + \omega t) \] (EQ 5)

and

\[ d'' = -D\omega^2 \sin(kx + \omega t) \] (EQ6)
From (1) the peak particle velocity is
\[ d'_{\text{max}} = D\omega = 2\pi f D \]  (EQ7)
and the peak maximum acceleration is
\[ d''_{\text{max}} = D\omega^2 = 4\pi^2 f^2 D \]  (EQ8)
Equations (7) and (8) are useful since they provide a method of approximating the maximum particle displacement and the maximum particle acceleration once the maximum particle velocity is known. It should be noted here that most seismograms are given as particle velocity-time records.
Figure showing scattered plot of collected data against standard by USBM
### APPENDIX 5

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Figure showing parameters to be used as a guide for blasters at Bengal Quarry