

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND
TECHNOLOGY
KUMASI

FACULTY OF MINING ENGINEERING
SCHOOL OF MINES, TARKWA

REAL AND PERCEIVED IMPACTS OF BLASTING AT TEBEREBIE
GOLDFIELDS LIMITED

BY

GOTTHOLD YAWO AGRA

MAY 2001

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REAL AND PERCEIVED IMPACTS OF BLASTING AT
TEBEREBIE GOLDFIELDS LIMITED

A THESIS PRESENTED TO THE KWAME NKRUMAH UNIVERSITY OF SCIENCE
AND TECHNOLOGY IN FULFILMENT OF THE REQUIREMENTS FOR THE
AWARD OF THE MASTER OF PHILOSOPHY (M.PHIL) DEGREE
IN MINING ENGINEERING

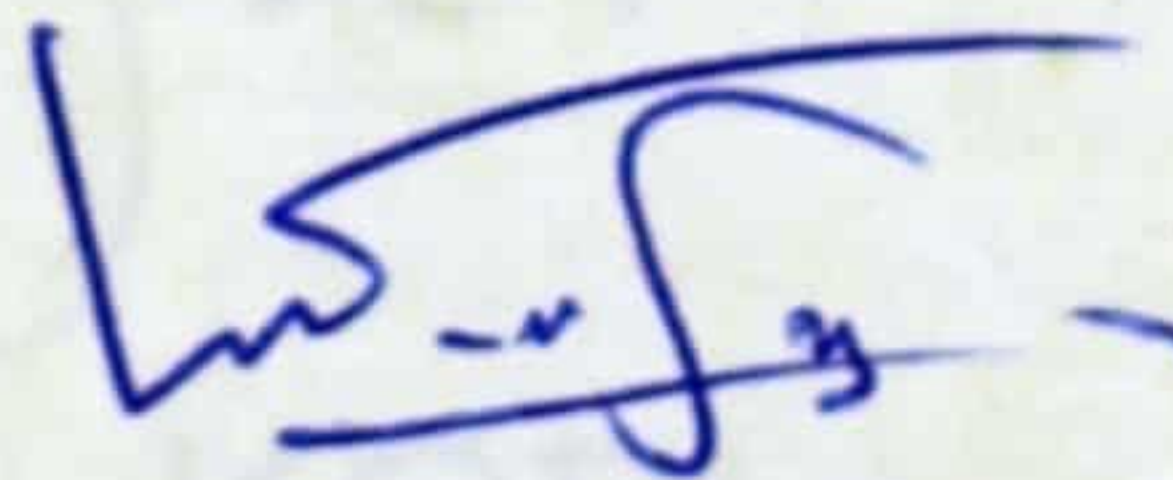
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TARKWA, GHANA

MAY, 2001

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DEDICATION

TO

GOD

MY WIFE AND MY CHILDREN

EDITH

KUDJOE

VERA

ALMA

AFI

KOFI

AND

DELALI

FOR LOVE, CARE AND

ENCOURAGEMENT

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ABSTRACT

REAL AND PERCEIVED IMPACTS OF BLASTING AT TEBEREBIE GOLDFIELDS LIMITED

Teberebie Goldfields Limited (TGL) is a company incorporated in the Republic of Ghana. The Pioneer Goldfields Ltd., Guernsey registered company holds 90% of the issued shares and the Government of Ghana holds the remaining 10%.

All mining operations are conducted using open cut mining methods, with a fleet of caterpillar mining equipment. Drilling and blasting form part of the normal sequence of mining operations.

Currently, all blasting is monitored using an INSTANTEL DS- 477 Blastmate II seismograph. The unit records the peak velocity, frequency at peak velocity, peak ground acceleration, and peak ground displacement in the transverse, vertical, and longitudinal planes. It also records the peak vector sum of ground velocities, the peak air overpressure and frequency, as well as the scaled distance.

No formula has yet been developed to predict the ground vibration levels for general geologic conditions and general blast design, and the most practical way to predict vibration level is to adapt the scaled distance formula to the site under consideration. There are also no current legal and recommended vibration limits for blasting in Ghana.

A study of blast vibration at Teberebie Goldfields Limited having different geo-mining conditions was executed. A total of over 1001 production blasts covering a time span between 1993 and early 1999 were monitored, and sample vibration data were collected. These were analysed and the validity of the available predictor models has been compared. Empirical correlation has been identified to estimate maximum explosive weight per delay for safe and efficient blasting. The study conducted on the mine identified the most suitable predictor model for calculation of charge per delay, so that a safe and efficient blast can be performed. Also questionnaire administration to assess the perceived impacts was undertaken.

This research has provided the necessary information that will create new ways of eliminating or reducing blasting problems in the future.

Teberebie Goldfields Limited should be able to benefit from an improved image, better operating practice and possibly reduce cost of drilling and blasting and not the least, the opportunity to sell the experiences to others.

ACKNOWLEDGEMENTS

Many thanks go to the Almighty Architect of the Universe for the strength and the guidance throughout this project work.

My sincerest thanks also go to my Project Supervisor Professor Dr. Newton Amegbey for his guidance, objective criticism and invaluable assistance.

To Teberebie Goldfields Limited and the Management and Staff, I say many thanks and I am very grateful to all of them. I wish to say special thanks to Mr. Bernard Ador formerly of Teberebie Goldfields Limited for his direction and useful information.

To my wife, I acknowledge her patience and prayers at all times during the period of the research and to my children for their encouragement.

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1.2. RESEARCH OBJECTIVES

- To study the present system of blasting in the area
- To establish the most suitable equipment for predicting ground vibration within the project area up to 100m
- To determine the social perception of blasting in the area

1.3. RESEARCH METHODOLOGY

- The study area was divided into three zones to be used in the study. The zones were defined in the study area and the results were compared with the results of the study area.
- Several different methods were used to collect data. The methods used were: direct observation, interviews, and questionnaires. The data collected was used to determine the social perception of blasting in the area.
- The study area was divided into three zones to be used in the study. The zones were defined in the study area and the results were compared with the results of the study area.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND (PROBLEM DEFINITION)

Environmental issues are playing and will continue to play a major role in how the Teberebie Goldfields Limited conducts its business. Practices of the past have created problems of misunderstanding, misperception and nuisance. The community is therefore faced with challenges of fear and nuisance due to blasting whilst there is no current legal and recommended vibration limits in Ghana.

With environmental regulations pertaining to mining operations becoming increasingly stringent, a thorough evaluation of the potential long-term effects of blasting is critical.

Currently, all blasting at Teberebie Goldfields Limited is monitored using an INSTANTEL DS- 477 Blastmate II seismograph. The unit records the peak velocity, frequency at peak velocity, peak ground acceleration, and peak ground displacement in the transverse, vertical, and longitudinal planes of the waves. It also records the peak vector sum of ground velocities, the peak air overpressure and frequency, as well as the scaled distance. In addition to recording the peak values listed above, the unit also records waveforms in the three planes among others.

1.2. RESEARCH OBJECTIVES

- ❖ To study the present system of blast monitoring
- ❖ To establish the most suitable relationship for predicting ground vibration within the geological set-up at TGL.
- ❖ To find what the public perception is of Blasting in Tarkwa area

1.3. RESEARCH METHODOLOGY

- Results from test sites to be used to illustrate factors that should be considered in predicting vibration effects on buildings and structures and also the nuisance it can create to people around.
- Several different literature sources were to be used in conjunction with available existing records of blast monitoring data and further tests shots to be performed using blastmates.
- Questionnaire Administration was used as a means of assessing the perception of the general population surrounding the Mine.

1.4. SCOPE OF WORK

- ❖ The work is to be limited to the sites where blasting currently takes place.
- ❖ Administrations of questionnaire to find out the perceived impacts within and outside the concession and included Teberobie village, Government Hill, School of Mines, Wangarakrom, Adisakrom and Tamso.

1.5. THESIS STRUCTURE

1. Chapter one outlines the background, objective of work, scope of work and thesis structure.
2. Chapter two provides the information on Teberobie Goldfields Limited.
3. Chapter three considers Drilling, Blasting and Ground Vibration.
4. Chapter four discusses Data Collection.
5. Chapter five treats Ground Vibration Modeling.
6. Chapter six presents Discussions, Observations and Findings and
7. Chapter seven deals with the Conclusions and Recommendations.

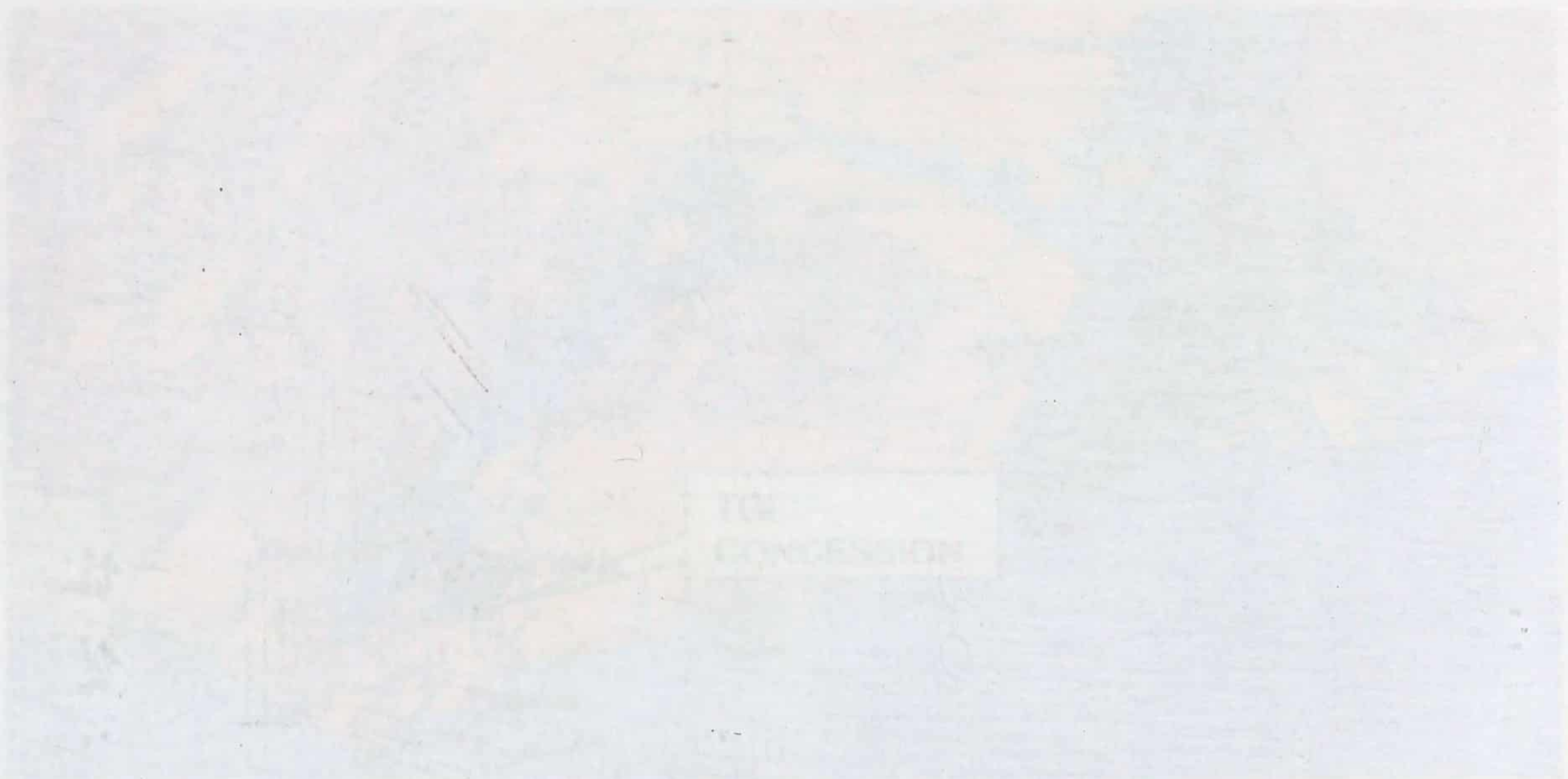


Figure 2.1 TGL Concession

CHAPTER TWO

INFORMATION ON TEBEREBIE GOLDFIELDS LIMITED

2.1 INTRODUCTION

Teberebie Goldfields Limited (TGL) is a company incorporated in the Republic of Ghana. The Pioneer Goldfields Ltd., Guernsey registered company holds 90% of the issued shares and the Government of Ghana holds the remaining 10%.

The local area has long been a center of mining activities with operating underground gold mines at Tarkwa and Prestea, and an open pit manganese mine at Nsuta, until TGL was formed to mine the low-grade ore. TGL employed as of 1998, a work force of some 1420 individuals, plus additional service contractors. TGL provides a high level of employment benefits and incurs direct payroll and burden costs in excess of one billion cedis monthly.

TGL has assembled environmental and socio-economic baseline line data and has produced Environmental Assessment documents for the initial mine and subsequent expansions.

2.2. LOCATION

TGL holds mining lease for a 42km²-concession area near Goldfields, Ghana Limited (GFGL) on the north and Ashanti Goldfields Company (AGC)-Iduapriem open pit mines on the south about 6km from the Tarkwa town. The concession shown in Figure 2.1 is close to the town of Tarkwa in the Western Region of Ghana. Tarkwa is about 330km by road from the capital city, Accra and linked by rail.

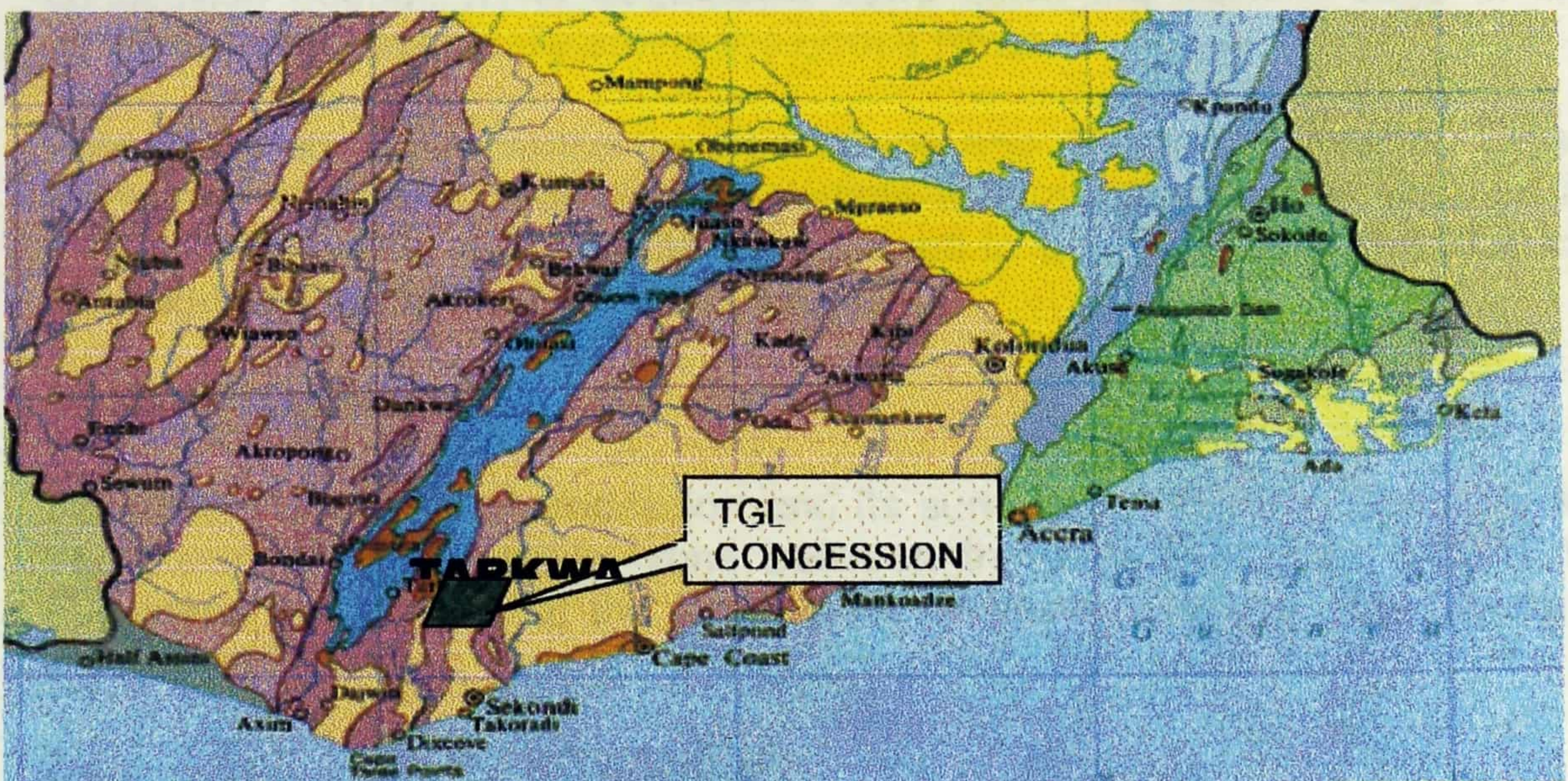


Figure 2:1 TGL Concession

2.3. CLIMATE

The Tarkwa region is characterized by a south-western equatorial climatic type influenced by the moist Southwest monsoon winds from the South Atlantic ocean and the dry-dust laden Northeast trade winds (known as the Harmattan) which blow over the Sahara desert from the northern sub-tropical high pressure zone.

The mean monthly temperature ranges from 24 to 28⁰C. The lowest monthly temperatures for the period are recorded in July/August rising to a maximum in February/March when cloud cover is least.

The annual rainfall pattern is a double maxima occurring in the months of April to June and from October to November. The mean rainfall is in the region of 1790 mm with average monthly rainfall ranging from approximately 33 mm in January to a maximum of 253 mm in June (approximately 35-year data at Tarkwa).

2.3.1 Surface Water

The Tarkwa area occurs within the Ankobra River basin of the Western region of Ghana. The TGL concession itself occurs within the Bonsa sub-basin of the Ankobra basin. Three small streams drain the TGL concession; these are the Ahumabru, Agonabeng and Bediabewu.

The main stream is the Agonabeng, which flows through the main operations area on the concession. The Ahumabru stream and its catchment area is on the western side of the concession and is largely unaffected by mining and other activities. The Agonabeng joins the Ahumabru downstream of the concession boundary. The Bediabewu flows down the eastern edge of the concession and eventually enters the Bonsa River.

Forest swamps characterize the Agonabeng and Ahumabru streams. These were the subjects of a detailed ecological and hydrological investigation in 1997 (SGS, 1997); which results were utilised in the Agonabeng river licence diversion application in 1997 (TGL, 1997).

2.3.2. Vegetation

Vegetation of the TGL concession and its surrounds has been classified as being part of the transition zone between the Wet Evergreen and Moist Evergreen forest types of the forest zone of western Ghana. (Jay Minerals Limited, 1990)

2.4. LAND COVER AND LAND USE

The original forest in the area has been severely disturbed by human activity prior to TGL's mining and replaced by secondary forest. It now comprises five distinct categories of vegetation as follows:

- Primary Forest occurring in small isolated areas on steep ridges in the central and southern fringes of the concession area.
- Swamp Forest occurring in low-lying areas.

- Secondary Forest occurring and covering the majority of the concession areas.
- Early successional vegetation occurring on recently abandoned farms.

Due to intense pressure from hunting, logging, and general human habitation over the past hundred years, the concession area is deemed to be of rather low ecological value. (Jay Minerals Limited, 1990)

2.4.1. Historical Land use and its socio-economic activity.

The TGL operations are in an area with a well-established mining history. (Junner, Hirst and Service, 1939) reported some 10,000 tons to 15,000 tons of ore extracted from the Teberebie-Awunaben areas in 1889. Prior to TGL's operations there were several adits leading into both the Teberebie and Awunaben deposits. In recent time the area has been the scene of much artisanal mining with the area pock marked by "galamsey" workings and the remains of their sluice boxes.

Prior to development by TGL, the concession area was typified by several human activities, past and present, which had altered the landscape quite considerably. Most of the concession area (c.80 percent or more) had been logged in the past and the remaining poorer quality woods were being harvested for the charcoal trade and for cooking fuel. Farming activities probably began after the loggers abandoned the area. These small farms were subsistence in nature and include cassava, oil palm, plantain, banana, cocoyam, citrus, rubber, and coconut.

Historically, the area was the site for several villages and hamlets, each with its nearby small farms. The villagers supplemented their income by artisanal mining (gleams mining). All these activities contributed to the general degradation of the vegetation and soils of the concession area. The resultant landscape was, therefore, comprised of a mosaic of abandoned farmlands, active farms and secondary forests at various stages of succession.

2.4.2. Villages and Hamlets in the Concession

Villages and Hamlets were scattered throughout the western concession area and are shown in Table 2.1. In some of the settlements one can count two to three huts

Table 2.1: Settlements in the Teberebie Concession and around

Settlement	Distance	Population
Teberbie/Pumpside/ Ntowkrom	1000m	600
Mandae/ Nsuekyir	Within concession	100
Wangarakrom/ Badukrom	Outside concession	400
Tamso/Atoabo/Government Hill		Population unknown

2.4.3. Relocation of Teberebie Village

Teberebie Village has been re-located and others have been resettled with adequate compensation packets. The inhabitants, who are migrants, originally went there to establish cocoa farms and rice farms. Due to acidic nature of the soils the cocoa farms did not do well and had to be abandoned. Some returned to their hometowns whilst others stayed and were later joined by illegal gold diggers.

In all the scattered settlements the migrants huts are generally of wattle and daub construction with rammed earth floors and thatched or bamboo roofing. Malaria was prevalent as disease.

2.5 WILDLIFE

Forest destruction through uncontrolled logging and hunting pressure had by the time of TGL development almost completely eliminated the large mammals typical of the forest regions of western Ghana. The Phase III Environmental Impact Assessment (EIA) (Jay Minerals Limited, 1990) reported from interviews with people in the small hamlets in and around the western half of the concession that common mammals still trapped included duikers, antelopes, grass-cutters and giant rats. Other mammals are now almost completely absent in the area due to human activity.

2.6 SOCIO-POLITICAL ENVIRONMENT

The concession is located in the Wassa West District, which is administered from the District capital of Tarkwa. The District covers an area of 244km². District Chief Executive, assisted by the District Co-ordinating Director, heads the local service. A District Assembly is in place with responsibility for overseeing local administration. Wassa West District Assembly is responsible for collection of local taxes and provision of health, welfare and educational facilities. It maintains feeder roads and constructs schools and KVIP toilets and markets. For a long time Tarkwa has experienced an influx of people from other regions of Ghana and elsewhere seeking for employment due to mining.

2.7 SOILS

The soils of the concession belong to the oxysol group which had been developed over siliceous Tarkwaian sandstone, quartzites and phyllites with two main soil associations namely: the Juaso-Manso Simple Association. The soils have no specific intrinsic properties, are heavily leached as a result of the high rainfall in the region and thus are acidic in reaction (pH 4.0 - 5.0). The top soils are more acidic than the lower horizons.

Organic matter content tends to be low and not considered suitable for arable agriculture because of susceptibility to leaching and erosion. The majority of the soils are considered suitable generally best suited for tree crops such as oil palm and coconut, and valley bottoms, which are underlain by poorly drained alluvial soils with clay contents, cover about 20% of the area.

2.8 GEOLOGY

TGL is located on the western limb of the Tarkwa Basin, a broad synclinal structure that contains fluvial sediments of continental origin and Pre-Cambrian age known as the Tarkwaian System. These sediments rest unconformably on a basement of metamorphosed sedimentary, volcanic and intrusive rocks referred to as the Birimian Series. Erosion of this basement sequence has supplied the argillaceous sediments of the Tarkwaian System.

The Tarkwaian System is approximately 2000m thick sequence of conglomerates, sandstones and siltstones. The gold mineralisation within the Tarkwaian System is contained within the Banket Series, a sedimentary unit 120m to 160m thick with horizons of quartz pebble conglomerates.

At the south end of the Tarkwaian Basin, the Banket Series is folded into a gentle, north-south trending syncline, which has been subsequently faulted and overtilted. Transverse faults have caused dislocation on the eastern and western limbs. Strike slip faulting and reverse-overthrust faulting has occurred.

The Banket Series has been subjected to lower greenschist facies grade of regional metamorphism and is intruded by dykes and sills of dolerite and form prominent ridges extending in a north-northeast direction for approximately 6 km from the concession boundary with Ghanaian Australian Goldfields (GAG) in the south. There are four ridges listed below from the north:

- | | |
|-------------------|----------------------|
| ▪ Mantraim Ridge | 2.4 km strike length |
| ▪ Awunaben Ridge | 1.2 km strike length |
| ▪ R 1 & R 2 Hills | 0.3 km strike length |
| ▪ Teberebie Ridge | 2.1 km strike length |

R 1 & R 2 Hills essentially form part of the Teberebie Ridge but the following descriptions will encompass them within the Awunaben area:

A massive lithological unit known as the footwall sandstone, which is a rock of blue grey colour exhibiting sub-parallel haematite/black sand banding, supports the Ridge segments. It forms the basal stratigraphic unit, locally to the Banket Reef Zone.

The Banket Reef Zone comprises a sequence of fining up units of polymitic pebble conglomerates (Banket Beds), breccia conglomerates, sandstones (now quartzites) and grits. These beds contain all the known gold deposits in the area. The upper stratigraphic limit of this zone is marked by the Hanging Wall Quartzite, a metamorphosed sandstones of buff colour, which exhibits well-developed and characteristic trough and cross-bedded haematitic black sand banding. The Hanging Wall Quartzite also contains thin discontinuous grit interbeds.

The conglomerates comprise matrix supported, well rounded to ellipsoid shaped pebbles of quartz, with varying proportions of sub-rounded to angular class of schistose metasediments and volcanics derived from the Birimian basement rocks.

Thin quartzite partings (sandstone interbeds) occur within the Banket conglomerates, whereas the breccia conglomerates grade into pebbly sandstones, locally termed grits.

Dykes and sills of dolerite types intrude the sedimentary sequences and occur adjacent to zones of structural complexity. All dykes are completely weathered at surface to ferruginous and seritic clays. Thin lentoid quartz veining is typically associated, spatially, with the dyke intrusions and the structurally disturbed zones. The majority of dykes appear concordant to semi-concordant with the main sequences i.e. are essentially sill-like in form, and have only rarely intruded the Banket Reef Zones sequences (adjacent to east/west dip faults)

Alteration is not significant in the Banket Reef Zone rocks. This either occurs as a regional lower greenschist facies metamorphism causing the development within the sequence of chlorite and muscovite micas including sericite.

2.8.1. Dolerite Dykes

Several dolerite dykes have been emplaced, discordant with the main sequence associated with the main fault systems, which separate the main blocks i.e. between Teberebie Ridge and R 2, R 2 and R 1, R 1 and Awunaben, Awunaben and Mantraim and Mantraim and Mantraim North. These major faults have acted as feeders for the dolerite emplacement before being intruded into the bedded sequence.

A dolerite dyke occurs in Teberebie Ridge outcropping at 12450N and separating into 2 no. dykes between 12700N and 13000N. This dyke is approximately 5m in thickness and has a similar dip to the bedding,

A series of dykes are present in the main Awunaben/Mantraim valley (14000N) but move into the footwall. There are no detailed geological sections immediately to the south of the fault zone so the continuation of these dykes in this direction is unknown. In this area the dolerite is weathered to full depth, which together with the general broken nature of the rock mass results in significant sequence of relatively poor quality rock.

2.8.2. Rock Mass Weathering

There is wide range in the degree and depth of weathering throughout the mine site. In the fault zones and on the sides of Teberebie Ridge the depth of weathered zones reaches to depths in excess of 100m. In the phyllites and areas close to the main fault the thickness of completely weathered rock reaches over 20m. These deep-weathering zones will have implications in respect of slope stability particularly in the main fault areas, Mantraim/Awunaben. Awunaben/R 2 and R 2/R 1 and to a lesser extent R 1/Teberbie, where both the endwalls (Mantraim/Awunaben) and sidewalls (Teberbie/Awunaben) will locally be formed in significantly weaker material.

In summary, the weathering profile does not extend to any great depth other than in the fault zone(s). In these areas there is likely to be an impact on both the groundwater inflow and on the stability of these areas where the excavations necessitate the formation of faces in this weathered material.

2.8.3. Faulting

Faulting within the mine site is evident with lateral displacements of 10m to 40m occurring along the east-southeast trending faults between Teberbie Ridge, R 1 & R 2 Hill and Awunaben Ridge. A dip fault with right-lateral displacement of approximately 150m exists between Awunaben and Mantraim.

A number of dip faults with between 2m to 10m of displacement are reported and low angle faults on Awunaben Ridge have resulted in apparent thickening of the rock units. The topography of the area is rugged consisting of series of ridges and valleys, the elevation ranging from 60m to 300m above sea level.

2.9. ENVIRONMENTAL IMPACTS

The major environmental impacts identified with TGL mining include land form alteration and associated sediment run-offs, possible soil degradation, water and air quality changes, noise, ground vibration, fly-rock and air blast during blasting operations, possible chemical pollution of rivers and water bodies, forest and vegetation cover destruction, etc.

2.9.1. Water Pollution and Water Quality Monitoring

Since 1992, TGL has undertaken routine surface water and groundwater sampling on the concession. In 1997 some 43 locations were being sampled monthly and analysed for pH, conductivity, total dissolved solids, total suspended solids, cyanide, some trace metals and other parameters. In 1998, following its annual environmental audit, the sampling program was reorganised. TGL's own laboratory (certified by the Ghana Standards Board) carries out analyses.

Previous audits and recent EIA (SGS 1998a, 1998b, 1997) found that current operations continue to have no discernible impact on the water quality.

TGL began construction to allow the controlled diversion of the Agonabeng stream and the containment of increased sediment that will result from continuing open pit development. Sediment arising will be diverted in a controlled manner to a new surface water impoundment.

The impoundment will form a large sediment trap for sediments arising upstream and prevent such sediment from leaving the concession. The retention of sediment by the impoundment will result in improved water quality in the downstream to the Bonsa River.

2.9.2. Air Pollution

Of the major sites, only the haul and access roads are significant sources of fugitive, or non-point source, dust. Except for very local sites, dust generation from the heap leach areas or the rock waste dumps is not considered environmentally significant. Neither is that from blasting or point sources such as the crushers, cement silos, and associated conveyors. Although, these various emissions may have a local "nuisance" level on occasion, none have any impact, even at a nuisance level outside the concession boundaries (SGS, 1998a).

TGL area is under the influence of the dust-laden Harmattan Winds. This seasonal particulate pollution occurs principally during the three months of the dry season from December to February.

2.9.3. Ground Vibration, Fly-Rock and Air Blast

Ground vibration, fly-rock and air blast also form part of environmental impacts and can cause damage to buildings and other man-made structures, cause nuisance, etc. to people, in much the same way as it happens in the fracturing of the rock material itself.

2.9.4. Blasting and Blast Monitoring

Blasting is monitored using an INSTANTEL DS- 477 Blastmate II seismograph. The Mines Department has a comprehensive set of regulations pertaining to safe explosive storage, handling, and use. These also cover training and qualifications for purchase and use. No Ghanaian regulations (either Mines Department or EPA) govern or limit blasting vibration, nor do any cover blast monitoring. TGL is unique in Ghana that it voluntarily monitors all blasts and adjusts variable blasting components to effect compliance with the selected US protocol in the absence of applicable Ghanaian Standards. Only a few metal mines do any blasting monitoring at all, and are essentially non-existent in any quarry operations.

2.9.5. Reclamation of Forest and Vegetation Cover Destroyed

Since mining causes degradation of the land, reclamation programs are put in place to minimise the effects and return them to near normalcy.

EIA's included initial Reclamation Plans. Until 1995, reclamation (i.e. revegetation) of areas disturbed by mining activity was not possible, as all areas on the TGL mining concession (the concession) were subject to various types and degrees of mine development. In 1995, the Company initiated its first reclamation program.

There was a contract with the Botany Department, University of Legon, and Accra to evaluate plant species adaptation on a completed heap leach area; subsequently, other revegetation research projects were initiated in 1996 and 1997.

In 1998, the Company carried out its first full-scale reclamation project using a commercial contractor. This continued on similar scale in 1999.

Development of a pragmatic reclamation and closure plan (Plan) for the estimated life-of-mine was put in place.

2.9.6. Noise

Various sources of noise are generated due to TGL mining activities through drilling, blasting, and crushing, vehicular movement, etc.

Hand held instruments by Precision Integration Sound Level Meter, Type 2236, Bruel and Kjaer is used in monitoring noise levels. Where there are indications of abnormalities efforts are made to minimise the effect and/or ear

plugs are provided and enforced to be worn at all times whilst at the place of the noise.

CHAPTER THREE

DRILLING, BLASTING, GROUND VIBRATION AND AIRBLASTS

3.1. DRILLING

Roger Holmberg of Swedish Detonic Research Foundation (1980) states that to attain good blasting results, it is essential to maintain accurate drilling and that the quality of drilling is vital to the success of the blast.

3.1.1. Drill Hole Sections

3.1.1.1. Bottom Charge

Blasting calculations commence by recognizing that the bottom section, which is the most restricted, demands a certain specific charge in order to break free. The bottom charge which is the charge located at the bottom of the hole is influenced by the burden and sub-drilling. Any explosive situated above the calculated height of the base charge does not influence the breakout at the bottom.

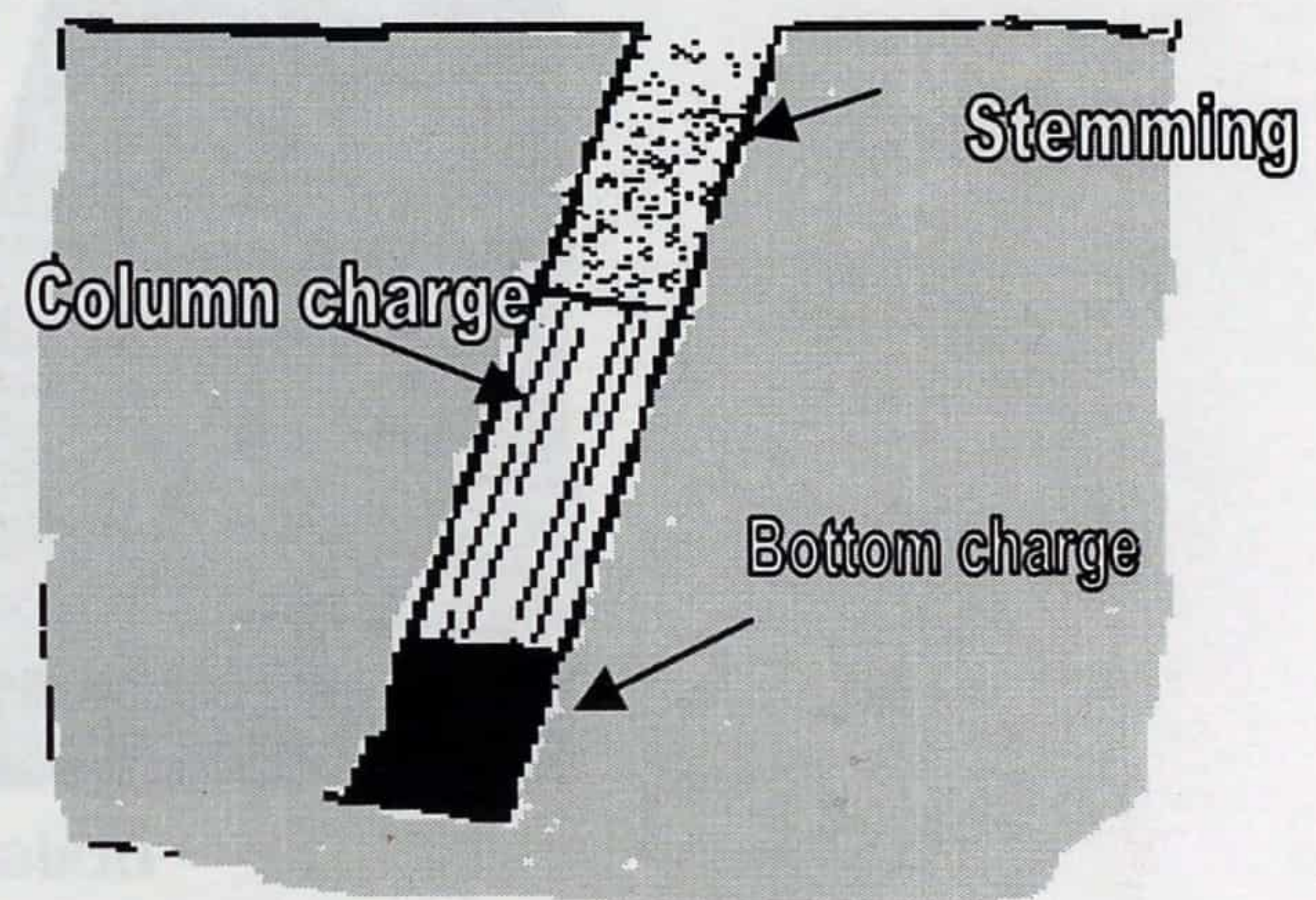


Figure 3.1: Drillhole Section

3.1.1.2. Column Charge

The rock lying above the bottom section requires considerably less charge concentration because of the lower constriction factor.

3.1.1.3. Stemming

Above the column charge, a section of determined length is left free of explosive and filled with sand (stemming). The length depends on the burden the risk for flyrock, and desired fragmentation. Figure 3.1 shows the various sections of a drill hole.

3.1.2. Hole inclination

To assist breakout in the bottom, it has been found that it is advantageous to incline the drill hole away from the vertical plane.

Figure 3.2 shows hole inclination 'a' that reduces the constriction factor, and gives, amongst others, the following advantages:

- Reduced specific charge
- Reduced specific drilling
- Better control of the blasting sequence, with a reduction in fly-rock results

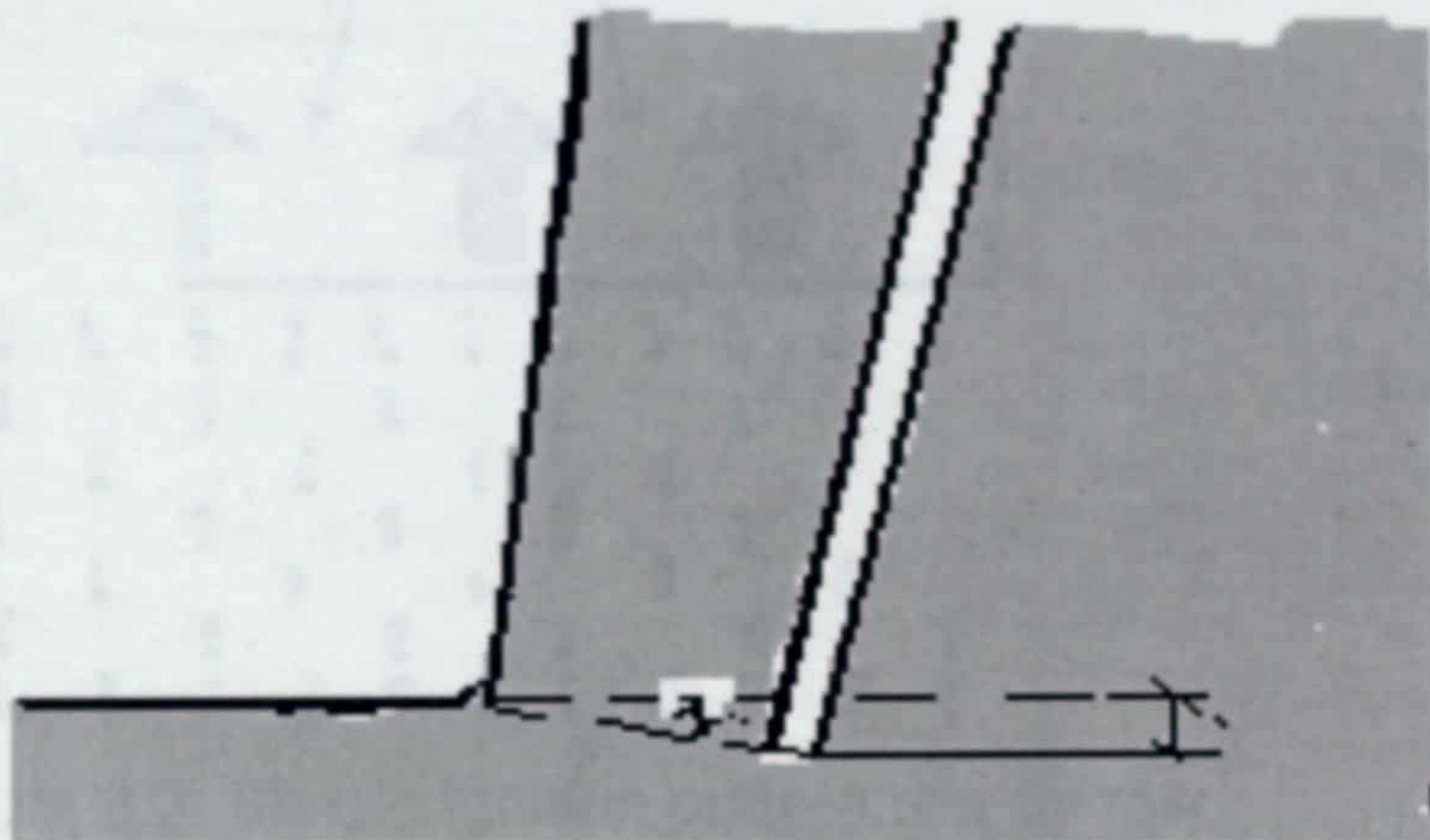


Figure 3.2: Hole Inclination

- Reduced risk for rock remaining in the bottom
- Reduced back-break
- Reduced ground vibrations
- Less risk for cut-offs

Hole inclination is especially important when the rock is extremely constricted, e.g., trench blasting.

Coarse hole diameters ($\geq 51\text{mm}$) and higher benches have been found to favour less inclined drill holes, which give the following advantages:

- Reduced faulty drilling
- Less risk for hung-up charges
- Increased packing degree when using plastic film cartridges

Hole inclinations are recommended as follows:

- Hole diameter $\geq 51\text{mm}$ 3:1
- Hole diameter $\leq 51\text{mm}$ 5: 1-10:1

3.1.3. Ignition patterns

A vital link in rock blasting is the ignition pattern (the way in which the round's delay is designed) and this is influenced by a lot of factors like conditions for discharge, fragmentation, mucking out, risk for fly-rock, ground vibrations, etc

Ignition pattern in Figure 3.3 enables the rock to be blasted free row by row, with the perimeter holes delayed by one interval. This allows the perimeter holes less constriction, which in turn puts less strain on the rock contour that is to remain.

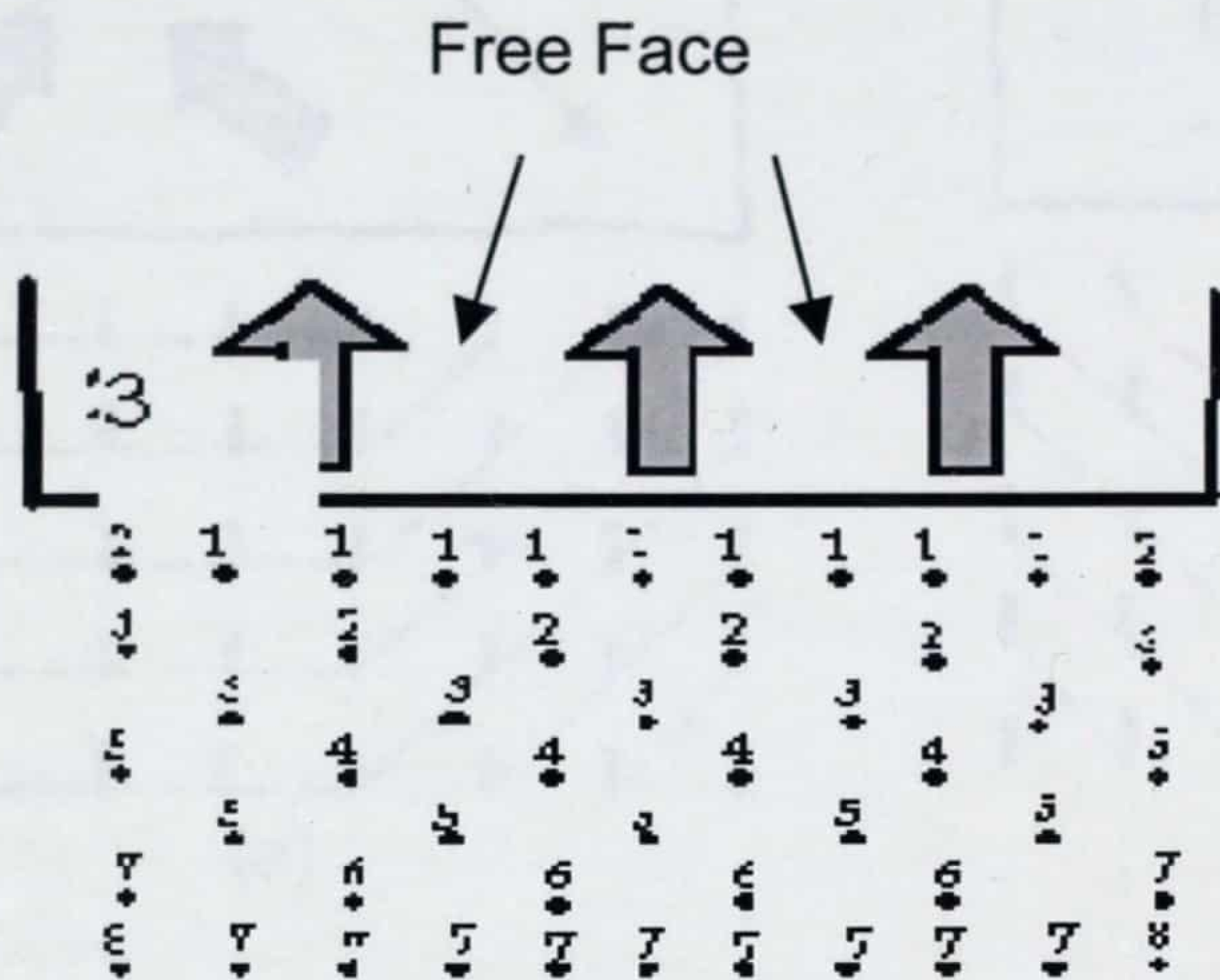


Figure 3.3: Simple ignition pattern row by row

A staggered ignition pattern, Figure 3.4, improves fragmentation.

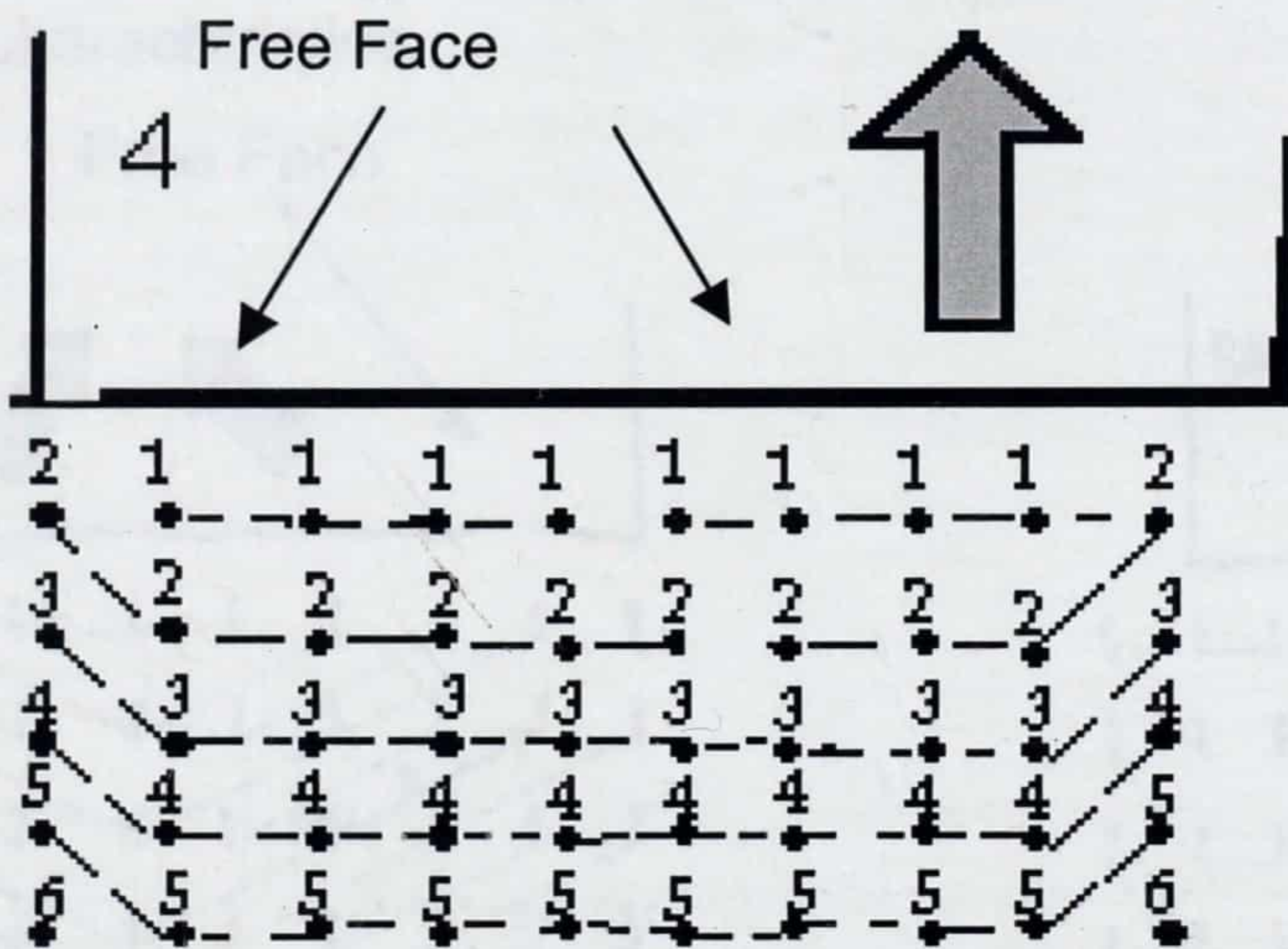


Figure 3. 4: Staggered pattern

Ignition patterns, Figures 3.5a & b, are of the symmetric plough formation type. This usually results in a better control of the blast's progression, and thereby reduces the risk for fly-rock. Also, a better-concentrated muck-pile is obtained which aids loading. Although the burden is consistently at right angles to the line of discharge, the relationship between burden and spacing changes. This change and the holes becoming staggered consequently, results in an improvement to fragmentation. Also aiding fragmentation is the

crushing effect obtained by the two sides of the blast being cannoned together.

Symmetric plough formations also help to reduce the rock's constriction factor and allow it to swell easier. The local rock conditions and the conditions relative to bench height/width influence the choice of angle of plough formation. A narrow bench required a more pointed formation to aid swelling

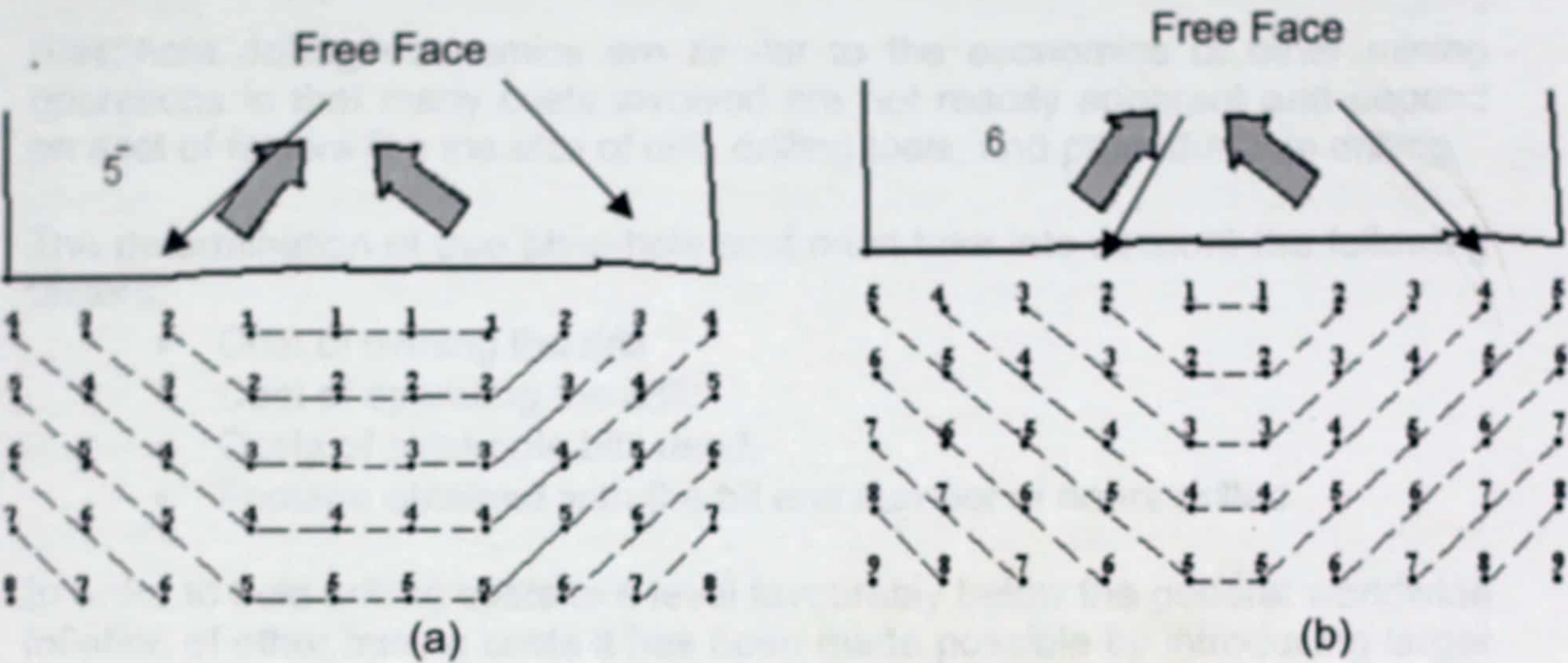
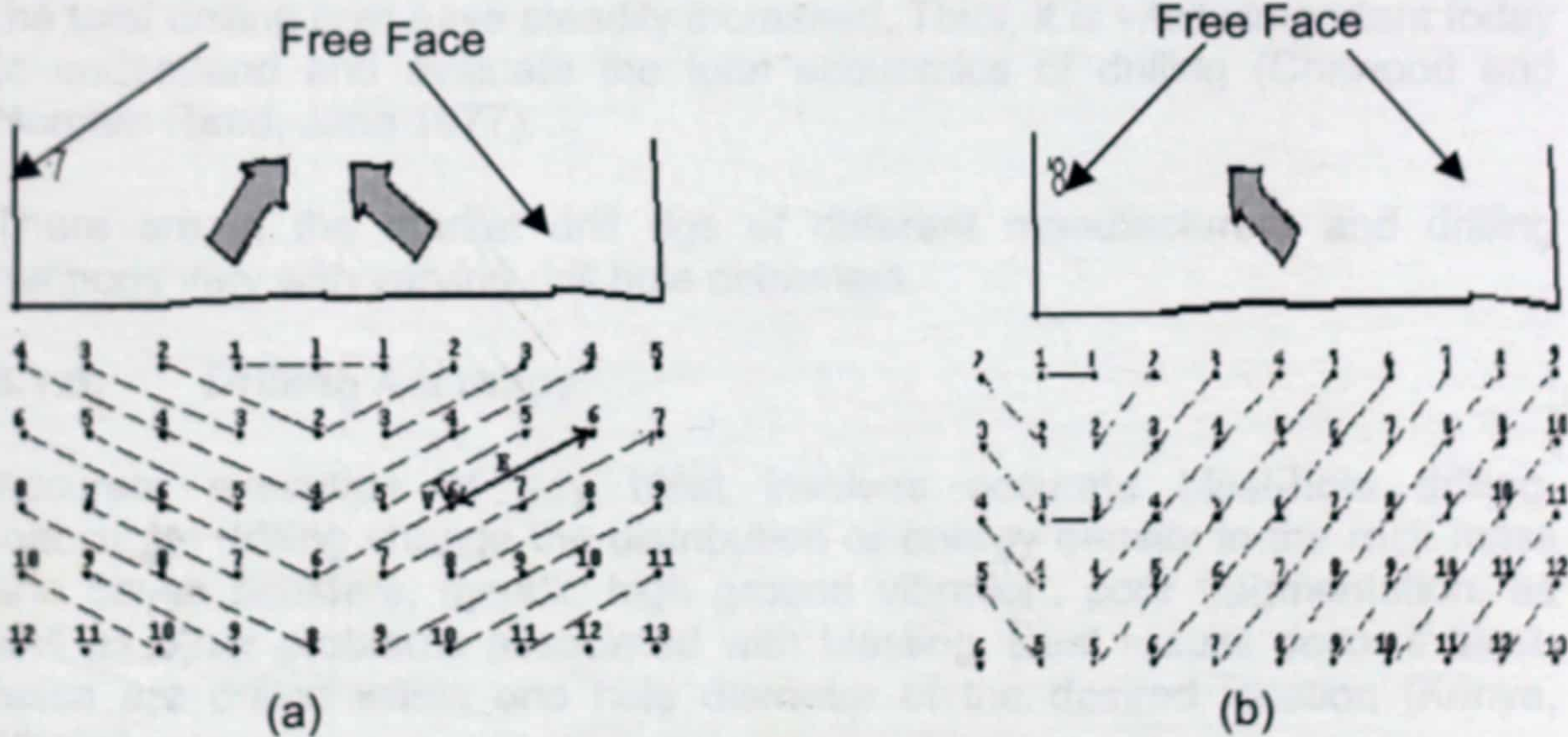


Figure 3.5a & b: Symmetric plough type

Usually, in Ignition plan, Figure 3.6a, & b, fired at obtuse angles gives finer fragmentation and can be used when it is desirable to limit the throw along the normal direction. This type of pattern can also be used to advantage of any geological characteristics.



Figures 3.6a & b: Fired at obtuse angles

3.1.4. Blast hole Drilling

Drilling is one of the most important aspects of blasting and must be evaluated to determine the average burden, average spacing and average drill-hole depths as well as the deviations, plus or minus, from this average (Konya, 1996).

Blast-hole drilling economics are similar to the economics of other mining operations in that many costs involved are not readily apparent and depend on a lot of factors like the size of drill, drilling tools, and procedures in drilling.

The determination of true blast-hole cost must take into account the following factors:

- Cost of owning the drill
- Cost of operating the drill,
- Costs of blast-hole bits used,
- Footage obtained with the bit and number of hours drilled.

In order to hold drilling costs to a level favourably below the general worldwide inflation of other mining costs it has been made possible by introducing larger and more powerful drills capable of applying higher down pressures and torque (Konya, 1996).

If products now in the planning stages reach the market, the day may not be far off when the mining industry will see 24-in (609.6mm), blast-holes being drilled at production speeds. Over the last 10 years, the diameter of a blast-hole, the down pressure on the bit, the wear on the rock bit and drill pipe, and the total drilling cost have steadily increased. Thus, it is vitally important today to understand and evaluate the total economics of drilling (Chitwood and Norman Reed, June 1977).

There are in the market drill rigs of different manufacturers and drilling methods vary with varying drill hole diameters.

3.1.5. Drilling Accuracy

Accurate execution of any blast involves accurate blast-hole drilling. Inaccurate drilling change the distribution or energy density in the rock mass and cause boulders, flyrock, high ground vibration, poor fragmentation, as well as other problems associated with blasting. Best results occur if blast-holes are drilled within one hole diameter of the desired location (Konya, 1996a).

It is important that the bottom of the holes is at the proper location and that the drill enters the ground at the proper angle in order to get proper blasting results. It is also important to have the proper dimensions on the surface for burden and spacing. These burden and spacing should be carefully measured before drilling and the holes should be measured after drilling. A statistical basis should be used to judge the accuracy of the driller and the pattern. If the

blast-holes are not drilled properly, the explosive cannot function properly and cannot compensate for the problems in drilling (Konya, 1996a).

3.1.6. Burden

The distance to free face on a blast-hole is the most important dimension in a blast. If blast-hole burdens are too large, the holes will not break to the entire depth. Very often toes are left in front of the blast-holes. Fragmentation also suffers if burden distances are large. When burdens distances are too small, rock will break fine, but it can be ejected into the pit, forming a low muck pile, and may cause fly-rock. Small burdens also result in higher cost and loss of energy. The burden distance also effects vibration. When burden distances are excessive, vibration increases dramatically as much as five times the vibration level that would occur with properly designed burdens (Konya, 1996b).

3.1.6. Spacing Dimensions

Spacing is normally defined as the distance between two blast-holes along the row as the row is firing. The spacing can cause two effects to occur. If the spacing is too close, pre-shearing can occur with fragmentation becoming coarse, and the walls between holes are commonly bowing inward into the solid. If the spacing distances are too far apart, the rock between holes is not properly broken and very often the face is seen bowing outward between holes (Konya, 1996b).

3.1.7. Control of burden and spacing pattern dimension

The Control of burden and spacing pattern dimension seems to be difficult task because of the need to quantitatively assess the drilling accuracy between one pattern and another. The general procedure is to measure all of the burden dimensions in the blast with tape and determine the mean value or average value of the burden and the amount of error for one standard deviation. Actual measures of the burden values are then made and the mean value and standard deviation calculated. Comparisons are then made between different drill operators and standards for drilling set using these criteria. This same procedure can be used with the spacing dimension as well as the depth of blast-holes (Konya, 1996b).

3.1.8. Blast-hole Depths

Correct blast-holes depths are extremely important in order to break to specific grade or floor level. It is not uncommon to find some blast-holes drilled deeper or shallower than the intended hole depth. Proper care should be taken to avoid either the deeper or shallow holes since they affect blast effectiveness (Konya, 1996c).

3.2. BLASTING VIBRATION WAVES

Vibrations and shock can be described mathematically as the way a body or particle moves in time. The time-dependent motion can be given alternatively in terms of displacement, particle velocity, or acceleration.

The simplest form of vibration is the simple harmonic movement, often called a sine (sinusoidal) vibration.

$$X(t) = A \sin(\omega t + \phi)$$

Where A (mm) is the displacement amplitude, ω is the angular frequency, t , is the time and ϕ is the phase angle.

For many practical applications, where the vibration can be approximated by a single sine wave, the phase angle has little significance. The vibration can be characterized by two parameters, like the amplitude and the frequency.

In dealing with wave interference, however, the phase angles of the interacting waves of course are of vital importance and for many other applications, it is important to know the vibration velocities in the three principal directions.

It can be shown that for the sinusoidal wave, the conversion between velocity and displacement (amplitude), by integration on the one hand, and between velocity and acceleration by derivation on the other, is equivalent to the division or multiplication of the velocity by ω , respectively, and the displacement in time by a phase angle equal to $\pi/2$ (Richart, 1970, Bollinger, 1980, Dowding, 1985, and Holmberg, 1984).

Variety of terms is used to describe the intensity of the vibrations and its variation in time. Different terms are used for different types of vibration depending on their nature (e.g. if they are continuous vibrations or transient vibrations). The characterization can be done in the time domain (description of lapse) or in the frequency domain (frequency spectrum). The latter is perhaps the more common.

3.2.1. Wave Motion

To predict what will happen to structures at a given distance from an excitation source, a fundamental knowledge of existing types of waves, how the wave motion is propagated, and how the structure in question is affected is necessary.

The compressional wave can also arise in ground and other solid materials, where it is often called a shock wave (P-wave).

In rock blasting, the most important surface wave is the Rayleigh-wave or R-wave. In this wave, the particles at the surface describe a retrograde elliptical motion. The vertical component of the particle motion has its maximum just below the surface, but thereafter diminishes relatively rapidly with the depth.

Different wave propagation velocities characterize the different wave types among others; the P-wave in turn is still a little slower than the S-wave which is the shear or secondary wave and moves through the medium at right angle to the wave propagation. The wave velocity is a function of the elastic properties of the material. At long distances from the source, the R-waves are often only distinguishable wave due to its much lower attenuation characteristics. The R-wave is longitudinal i.e. has vertical retrograde (backwards) motion. These waves are common, carry the major part of the surface ground energy and consequently cause the most damage.

Q-waves cause transverse vibrations (side-to-side) in the horizontal plane with no vertical displacement.

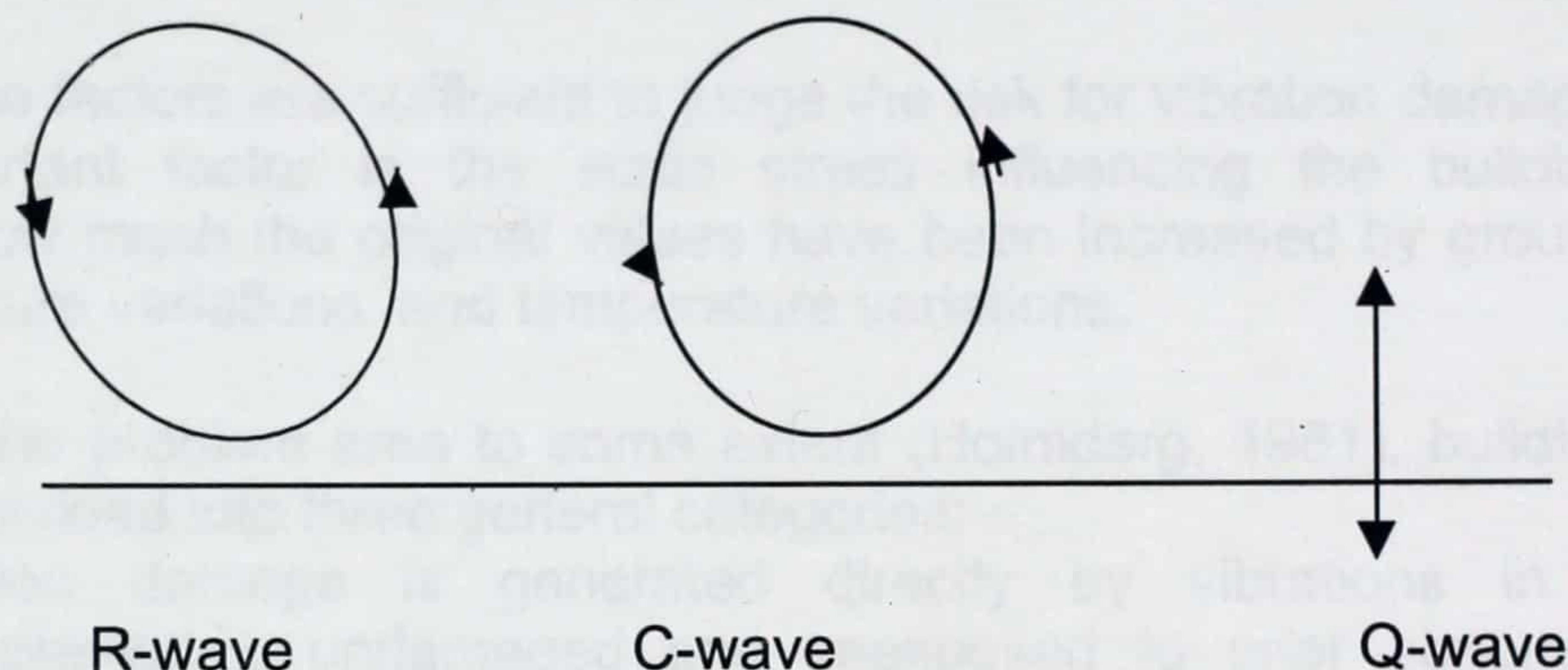
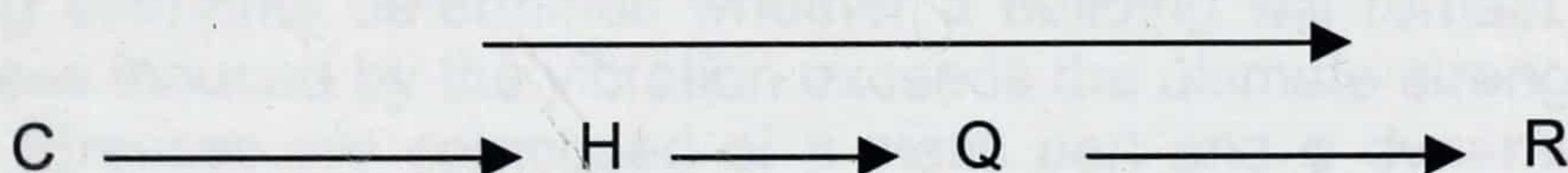


Figure 3.9: Particulate Motions Associated with R, C and Q Surface Waves.

A variation of surface waves is the coupled or C-wave (having both vertical and horizontal displacement). A reverse of the R-wave is the H-wave (only found in nuclear blasts) Figure 3.9 illustrates some various types of waves. Surface waves are characterised by the following decreasing order in velocity:

Decreasing velocity



Explosions in the ground are generated under a variety of conditions and this may lead to the formation of one type only, all types or combinations of surface waves. In dealing with environmental problems it is the net resultant motion to which a structure or person is subjected to which is of interest and hence it is usual to measure the net effect of all surface waves.

The wavelength for a periodic wave is the distance measured transversely to the wave front between two successive points with the same motion phase

For a wave with frequency f and propagation velocity, c , the wavelength $\lambda(m)$

$$\lambda(m) = c/f$$

The wavelength is a parameter of great significance for the influence of vibrations on different structures.

3.2.2. Damage to Buildings

The connection between vibration and damage to buildings is a complicated one for many reasons. Buildings are constructed in many different ways; some solidly built than others with different dimensions, materials, methods of construction, and types of foundation. Moreover, the intensity, type, frequency range, and wavelength of the vibrations and the direction of incidence of the wave front relative to the main axis of the building structure all play an important part in the origin of damage.

Not even all these factors are sufficient to judge the risk for vibration damage. The most important factor is the static stress influencing the building elements, and how much the original values have been increased by ground settlement, moisture variations, and temperature variations.

To systematise the problem area to some extent (Holmderg, 1981), building damage can be divided into three general categories:

- ❖ Direct vibration damage is generated directly by vibrations in a construction previously undamaged and unexposed to prior abnormal states of stress.
- ❖ Accelerated ageing are caused by dynamic stresses from vibrations due to buildings not founded on solid rock and are more or less damaged over time by settlement in the foundations and
- ❖ Indirect vibration damage due to settlements that can later result in damage to buildings.

3.2.3. Primary Damage Criteria

The relation between applied stress and strain, and the strength of the building elements determines whether a building will remain undamaged. If the stress induced by the vibration exceeds the ultimate strength, damage will occur. Stresses are composed of a static part and a dynamic part and that their sum is important. The dynamic stress is initiated directly by the vibrations, while applied loads and prior deformations of the construction, most often acting over a long period, determine the static stress. Standard values for permitted vibrations based on experience are used. These values take into account the type and condition of the building, the state of the foundation, and the types of vibrations. The standard values used today cannot guarantee that new damages will not occur (even if the vibration level never exceeds the standard value); yet based on a great deal of experience, damage will occur only in a limited number of cases.

From a study of blasting vibrations, a set of reliable standard values has been established by Holmderg, et al, [1981] and refers only to direct vibration damage. Accelerated ageing can occur even at very small vibration levels and it is impossible to use standard values, which would exclude this type of damage. To attempt this, would be equivalent to stating that no disturbance

would be acceptable. An experiment, (Stagg et al, 1984) showed that the household activities resulted in strains corresponding to blast vibration levels equal to 22.4 mm/s and the daily environmental changes gave a corresponding blast level equal to 76 mm/s

3.2.4. Limiting Vibration Levels for buildings and Installations

The need for vibration measurement, which would facilitate the management of blasting work, is important, as it has been shown directly proportional to the stress to which the building material is exposed. The relationship between particle velocity and stress in an idealised case, when a plane shock wave passes through an infinite elastic medium, is normally expressed as

$$\gamma = v/c$$

Where γ = shearing angle (mm/m)

V =peak particle velocity (mm/s)

C = propagation velocity of the seismic wave (m/sec).

The formulae indicate that the propagation velocity of the waves is very important (Olofson, 1988)).

Table 3.1 shows the Limit Values for the vertical particle velocity v (in mm/s) for building damage (Langefors and Kihlstrom, 1963).

Table 3.1: Limit Values for the vertical particle velocity v (in mm/s)

Ground Material Beneath Buildings	sand, gravel, clay (mm/s)	Moraine, slates, soft limestone (mm/s)	Granite, igneous, hard limestone, quartzite, sandstone, diabase (mm/s)	Results in normal residential area
	18	35	70	No noticeable cracking
	30	55	110	Fine cracks, and fall of plaster (threshold value)
	40	80	160	Cracking
	60	115	230	Serious cracking

and Table 3.2 also shows a compilation of recommended limit values used in Swedish rock blasting when judging the risk for damage by ground vibrations in normal residential areas.

Table 3.2: Recommended peak particle velocities in Germany according to DIN 4150 [1975]

Building class	Maximum resultant of the particle Velocities v_r (mm/s)	Estimated maximum vertical particle velocity v_z (mm/s)
I) Residential buildings, offices and others similarly built in the conventional way and being in normal condition	8	4.8-8
II) Stable building in normal condition	30	18-30

For old buildings of inferior quality on rock foundations it is common to reduce the permitted particles velocity from 70 mm/s to 50 mm/s and to 35 mm/s for light concrete buildings. Corresponding adjustments are also made for other types of foundations. Many values exceeding 110 mm/s have also been registered without causing damage to solidly constructed buildings. Heavy concrete constructions founded directly on rock can withstand single blasts up to 150 mm/s. The values indicated in Table 3.1 are empirical and based on more than 100,000 measurements.

The dominant frequencies for vibrations transmitted through soft rock, moraine, sand gravel, and clay is lower than that for vibrations transmitted through hard rock such as granite.

In many parts of the world, including Ghana, there are no regulations defining limits to the vibration levels in buildings. The above recommendations in Tables 3.1 and Table 3.2 serve as a guideline to prevent or limit building damage to a practical level.

Extensive studies have been carried out by the US Bureau of Mines (Siskind et al., 1980) to review earlier research concerning structural damage from vibrations to carefully monitor building response, and to make recommendations for what peak particle velocities the blast operator will not exceed.

A maximum peak particle velocity of 0.75 in/sec (19 mm/s) is recommended in the frequency range, $f = 4-12$ Hz when gypsum is used for the interior walls of the structure. A lower peak particle velocity of 0.5-in/sec (12.7mm/s) is recommended when plaster cracking can occur. The recommended value of 2 in/sec (50.8 mm/s) for $f > 40$ Hz is based on the lowest vibration velocity level at which damage was observed, 2.2 in/s (56mm/s) (Siskind, 1980).

Over the years, the authorities successively lowered the limits and finally in 1989, a Swedish Standard, SS 460 48 66, was accepted and revised in 1991. This standard is extremely helpful for calculation guidance levels for blast induced vibrations for buildings. These Guidance levels are used for establishing permitted vibration levels or threshold values and used only the

vertical peak particle velocity but prescribes that for certain situations three-component measurements must be performed.

Guidance Level values are based on a broad, well-documented correlation between the vertical peak particle velocity component and induced damage to buildings founded on various types of geological ground. The guidance level v (mm/s) is given by:

$$v \text{ (mm/s)} = v_0 F_K F_d F_t$$

where v_0 denotes the uncorrected vertical peak particle velocity in mm/s.

F_K is a construction quality factor, F_d is the distance factor, which considers the distance from the round to the measuring gauge, and F_t is a factor describing the project time for blasting work, for example, long-term mining activities or short-term construction activities

3.2.5. Distance Factor

The distance factor F_d is a function of the shortest distance between the round and the building of concern.

3.2.6. Project Time Factor

The project time factor F_t , depends upon the duration of the blasting activity and uses sliding scale depending upon the length of time of the project.

3.2.7. Vibration Level, Distance, and Charge Weight

As rock is not an isotropic medium, it is often hard to predict the vibration level at a given distance. It is apparent that the different types of waves generated are dampened differently, depending on the strike and dip of occurring foliation or bedding. The schistosity, the distance between existing planes of weakness, and fluctuations in the groundwater level can affect the vibrations. Additionally the blasting geometry, the performance of the explosives, the coupling between the explosives and the rock, and the distribution of the ignition time intervals in the round also affect the vibrations.

In most cases, the maximum particle velocity (mm/s) is used to express what vibrations the actual object can withstand without being damaged when blasting is carried out. The investigations made by Langefors and Kihlstrom, 1963 show that a usable empirical relationship between particle velocity v (mm/s), weight of charge W (kg/delay), and the distance R (m) is

$$v = \frac{K}{[R/\sqrt{W}]^\alpha}$$

where the constants K and α vary with the foundation conditions, blasting geometry, and type of explosives. To use the empirical formula, above, to reliably predict the vibration level for a determined distance, the constant K and α should have been determined by test blasting in the vicinity of the blasting place.

Explosive charges are set off to determine the transmission properties of rock mass and thus provide a basis for determining the charge size in the main blast. In this way, any possible damage to neighboring structures could be prevented.

The test charges in the test blast are placed on the line between the building that could be damaged and the blasting site. The actual vibration intensity is registered (e.g., peak value of the particle velocity). It is insufficient to measure only the peak values of the acceleration, particle velocity, or displacement therefore, the time history of the vibration must also be recorded and stored for analysis. After recording the particle velocity, the measured peak values are analyzed. A regression line is drawn through the number of discreet points.

As part of the risk analysis, an investigation must be made of the built-up area for vibrations and a maximum vibration level for nearby buildings and sensitive objects determined. The intersection between the damage criterion and the regression line gives the lowest $R/W^{1/2}$ value allowed to be used. For each distance, a unique weight of charge that must not be exceeded will then be determined.

The regression line is not an upper limit for measured particle velocity. It is probable that the damage criterion will be exceeded, if the intersection point between the damage criterion and the regression line is used to determine maximum weight of charge. An addition of a safety factor to the damage criterion is always necessary because of the risks anticipated.

To find the best regression line, $v = f(R, W)$ to the variables, the constants a, b, and c for the equation must be determined as in:

$$v \text{ (mm/s)} = a W^b R^c$$

Usually, it is assumed that constant b is equal to c/2, which gives us the square root scaling

$$v \text{ (mm/s)} = a (R/\sqrt{W})^c$$

which has the form $y = \alpha + cx$; that is, a straight line.

3.2.8. Scatter of the Peak Velocity

When the peak particle velocities are plotted vs. scaled distance (e.g. $R/W^{1/2}$), it will be seen that there exists a fairly large scatter about the mean regression line achieved for a least squares fit of the logarithmic values.

A number of factors can be responsible for the scatter at a given scaled distance which might include geology, confinement conditions, type of explosive, rock properties, cooperating charges, delay times, different wave types, and errors in measurements and analysis.

3.3. ENVIRONMENTAL IMPACTS

3.3.1. Ground vibrations.

Ground vibration is an integral part of the process of rock blasting. The sudden acceleration of the rock by the detonation gas pressure acting on the drill-hole walls induces dynamic stresses in the surrounding rock mass. This sets up a wave motion in the ground and spreads concentrically from the blasting site, particularly along the ground surface and is therefore attenuated, since its fixed energy is spread over a greater and greater mass of material as it moves away from its origin. Even though it attenuates with distance the motion from a large blast can be perceived from far away. Humans and animals alike react to the faint motion with reflexes of alert and fear.

In the near region, the ground vibration can cause damage to buildings and other man-made structures by causing dynamic stresses that exceed the building material's strength, in much the same way as it happens in the fracturing of the rock material itself. A building, being much less rigid than the solid rock mass, can be damaged even a long distance away from a carelessly designed blast.

The ground vibration effects of blasting operations on building structures and human beings need to be predicted, monitored and controlled. Without this prediction, it can increase the blasting cost to such varying extent, and result in damaging nearby buildings (Holmberg, 1984).

3.3. 2. Air Blasts and Ground Vibrations damage from Blasting

The problem of determining what effect the air and ground vibrations have on structures is especially acute for surface operations. The general public is directly involved in the blasting vibration problem; it is major concern to government as well as to mining companies, explosive manufacturers, insurance companies and scientific investigators. Consequently many investigations have been conducted on the effects of air and ground vibration on residential and other structures.

The United States Bureau of Mines in 1939 -1942 conducted an extensive investigation on the problem of seismic effects of quarry blasting and established damage criteria for residential structures based on experimental data as follows:

Acceleration of less than 0.1 was considered safe, 0.1 to 1.0 g was caution 0.1 and greater than 1.0 g was damage.

Because of anticipated complaints and lawsuits that may result from claims of damage by property owners, research was undertaken. Langefors, Kihlstrom, and Westerberg (1957) established set damage criteria based upon the particle velocity of ground motion in the vicinity of the structure and adopted blasting codes, which would suit the area. The damage criteria used in these

codes varied considerably, were based on displacement, on acceleration and some on energy ratio, and are presented in Table 3.3.

Table 3.3: Four designated levels of damage.

Researcher	Particle Velocity	Level of Damage
Langefors, Kihlstrom & Westerberg (1957)	2.8in/sec or 71mm/sec	No noticeable damage
	4.3 in/sec or 109mm/sec	Fine cracks and fall of plaster,
	6.3 in/sec or 160mm/sec	Cracking of plaster and masonry walls
	9.1in/sec or 231mm/sec	Serious cracking
Edwards & Northwood (1959)	Less than 2 in/ sec or 50mm/sec	Considered safe
	Between 2 and 4in/sec or 50mm/sec and 102mm/sec	Caution
	and above 4 in/sec or 102mm/sec	Damage
USBM (1960)	2in/sec or 50mm/sec	Safe

3.3.3. Air Blast.

It was realized that airborne vibrations were the reason for many of these complaints not from the point of view of damage but from the point of view that when a property owner hears an air blast he immediately looks for possible damage to his house. In 1960, Perkins, Lorraine and Townsend showed that local atmospheric conditions were responsible for focusing of air blasts and that these focal points were centres of many complaints and some damage. They also outlined methods to determine when focussing of air blasts would not occur.

The recent United States Bureau of Mines work in 1964 has also shown the need for more accurate instrumentation to measure the vibration levels at various distances from the blast. A general propagation law was developed which makes possible the prediction of vibration levels from only the charge size per delay interval and the distance from the blast point (Devine, Berk, Mayes and Edge, 1964)

More recently, research work has been conducted on the possibility of air-blast damage. Results from some of this research indicate that an overpressure of less than 0.1-psi. (689.5Pa), should be safe from the point of view of damage to window panes and of damage to plaster from structural vibrations (Mayes and Edge, 1964).

While cracked plaster is the type of damage most frequently mentioned in air-blast complaints, research (Mayes and Edge, 1964) has shown that windowpanes fail before any structural damage. In fact a poorly mounted windowpane can fail when subjected to peak overpressure as low as 0.1 pound per square inch (psi) (689.5Pa)). Damage to properly mounted windowpanes can be expected when air blast pressures approach 1 psi (6894.8Pa)

CHAPTER FOUR

It is interesting to note that air-blast pressures of only 0.003 psi (20.7Pa) can cause a loose window sash to rattle against window frame. While this causes a loud noise, no actual damage is done, but it can be a frequent source of annoyance complaints (Mayes, W. H. and Edge, P.M. 1964).

This section discusses the method employed in collecting the relevant data and information. The questionnaire format used is shown in Appendix 1.

CHAPTER FOUR

DATA COLLECTION AND RESULTS

4.1. INTRODUCTION

This section discusses the method employed in collecting the relevant data and information. The questionnaire format used is shown in Appendix 1

4.1.1. Administration of Questionnaire

Data was collected in two ways through interview of the illiterates and distributing questionnaire to the literates to be returned after completing them. Emphasis was placed on the supposed affected or impacted areas due to blasting. The chiefs and opinion leaders were considered to be in position to offer unbiased information. Nonetheless others were also involved

Questionnaires were administered to nine villages in 1999. These villages are Wangarakrom, Badukrom, Adisakrom, Teberebie Village, Bankyim, Tamso, Government Hill, Atoabo and Bogosu.

In addition to the interviews a limited number of questionnaires were circulated.

The questionnaires administered and the total respondents are given in Table 4.1.

Table 4.1: Questionnaires administered and the Total respondents

Village	Total Questionnaires		Questionnaires received	Total Respondents
	Administered	Interviewed		
Wangarakrom & Badukrom	10	5	6	11
Adisakrom	5	3	2	5
Teberebie Village	6	6	4	10
Bankyim	12	7	7	14
Tamso	4	2	3	5
Govt. Hill	4	1	2	3
Atoabo	4	2	2	4
Bogosu	3	4	1	5
Total	48	30	27	57

4.1.2. Reliability and validity of Data and Information

Most of the respondents involved in the study have stayed at these villages for some time and have experienced what mining has done to their lives and for that matter, the data and the information to greater extent may be said to be reliable and valid. Their views on the blasting impacts therefore could be considered reliable but are in some cases loaded with inconsistencies.

4.1.3. Limitation of the Study

It may be reasonable to conclude that the percentage response rate (%) was quite high and above 70% since people showed interest. This places a high premium on the generality of the views expressed by the respondents.

4.1.4. Results of the Questionnaire Administration

The following results were obtained:

1. 70% of the respondents were male and were all above the ages of 18 years.
2. 60% lived at these areas for more than 5 years and claim they have experienced some type of blasting underground went on but which surprisingly did not disturb them.
3. Since TGL started blasting at the surface it disturbs them so much without understanding why.
4. In an answer to a question as to what they think are some of the effects of blasting the following emerged:
 - ❖ Blasting is done randomly and this affects their social life.
 - ❖ Blasting has caused cracks to appear in their mud houses.
 - ❖ Due to dust emitting from the blasts they claimed this leads to tuberculosis and chest problems.
 - ❖ The atmosphere is polluted with gaseous air resulting in acid rain, making the water unwholesome and making people sick of various diseases
 - ❖ The blasts cause vibration of the earth, their buildings and everything
 - ❖ They experience occasional dripping of the eyes with tears resulting in eye problems
 - ❖ People especially who have high blood pressure experience shock when they hear the blast
 - ❖ During blast there is always terrible disturbing noise causing nuisance to them
5. In a related question 70% of them answered yes that the negative effects being experienced were lodged as complaints to the following:
 - ❖ Hospital Staff of the Tarkwa Government Hospital
 - ❖ Medical practitioners of some of the Hospitals and Private clinics
 - ❖ Senior officers of TGL
 - ❖ Workers of TGL
 - ❖ Medical Field Unit of Tarkwa
 - ❖ Branch union of TGL
 - ❖ Commission on Human Rights and Administrative Justice
 - ❖ District Environmental Management Committee

Unfortunately there was no response from the authorities except the District Environmental Management Committee. However, majority of the problems remains unsolved

6. The majority of the respondents suggested that the following should be provided by TGL if they want to continue mining:
 - ❖ Give incentive packages to surrounding villages
 - ❖ Resettle the affected people
 - ❖ Stop blasting and adopt other measures
 - ❖ Take appropriate measures to provide clean and safe environment
 - ❖ Find antidotes to the problems associated with blasting
 - ❖ Provide good drinking water
 - ❖ Find other methods of extracting the gold without blasting
 - ❖ Find modern methods of blasting to reduce the impacts
 - ❖ Provide free medical facilities to all the villages within and outside the concession area
7. On why TGL blasts, 80% said that blasting is done due to the following:
 - ❖ Just to disturb them
 - ❖ To make money at the expense of the locals
 - ❖ To get easy access to the gold and other minerals
8. On severity of the effects of blasts 90% reported that it was so severe as if it was an earthquake

4.2. BLAST MONITORING

4.2.1. Production Blasts

Series of blast monitoring was executed at the Mines, Government Hill, and, Teberebie village between 1997 and February 1999. Before this period there were series of production blasts, which were also monitored between 1993 and 1996. These are presented in Table 4.2.

Table 4.2: TGL. Blast Summary showing sampled blasts used for analysis at Teberebie Village and Government Hill

PERIOD	EVENTS	SAMPLED BLASTS	LOCATIONS
24/5/95-19/8/96	150	0	Teberebie
19/8/96-5/3/94	149	0	Awunaben
8/3/94-23/4/96	148	0	Mantraim
23/4/96-29/6/98	150	8	Government. Hill
29/6/98-30/3/98	148	29	Teberebie Village
30/3/98-28/3/99	106	0	Mine Office and Old Magazine
TOTAL	1001	37	

4.2.2. Test shot and monitoring

Two Test shots were performed in the Awunaben ridge pit around the old magazine and monitored at both near the old magazine shown in Figure 4.1.

and Govt. Hill. Two (2) similar Monitors were used to measure the blasts. This was to determine the seismic profile of the waves, which are measured at various points giving information on how the characteristic of the rock varies and to assist in the determination of the site constants. Results are indicated in Table 4.3.

Table 4.3: Results of two Test Blasts with 2 monitors

Date	Time	Location	Q, (kg/delay)	R, (m)	V, (mm/s)	Scaled distance (m)
29/1/99	13:56:49	Magazine	1050	350	10.4	10.8
29/1/99	13:57:00	Magazine	1050	1000	5.52	30.9
30/1/99	15:42:22	Govt. Hill	720	1650	1.03	61.5
30/1/99	15:42:35	Govt. Hill	720	1800	1.08	67.1

V = Peak particle velocity (mm/s)

R = distance of the measuring transducer from the blasting face (m)

Q_{max} = maximum charge per delay (kg)

Scaled distance = $(R/W^{1/2})$,

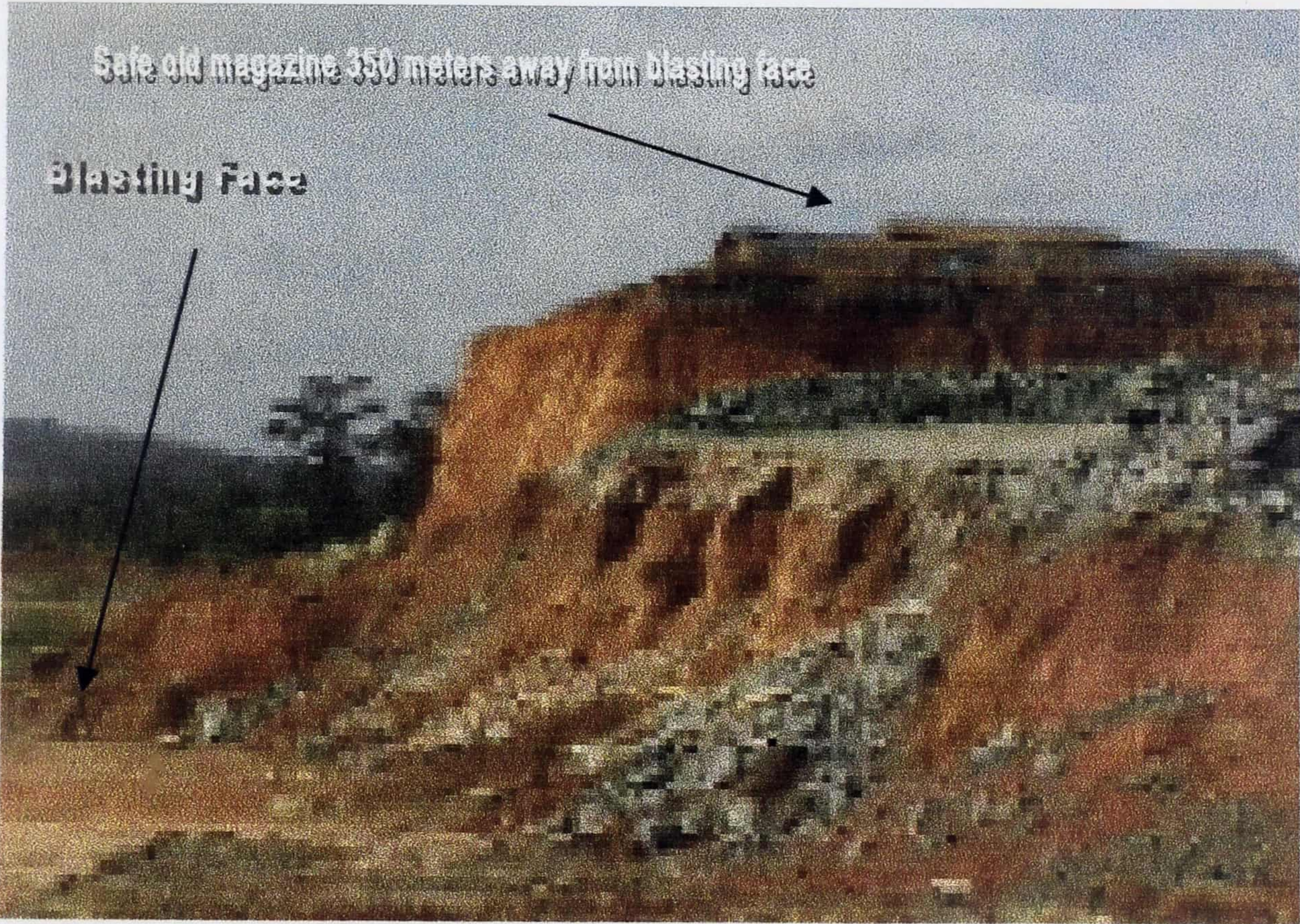


Figure 4.1: Safe old magazine 350 meters away from blasting face

CHAPTER FIVE

GROUND VIBRATION MODELLING

5.1. MODEL DEFINITION

A model is a device, which behaves approximately like part of a real world; it is an abstraction of reality. It can be a physical, conceptual, schematic or mathematical representation of life object or situation or natural phenomenon (Mireku-Gyimah, 1998)

Ground Vibration Modelling is to establish the most suitable Blast Predictor models for calculation of charge per delay for safe and efficient blasting devoid of possible damages and disturbances to the community in the District

5.1.1. Modeling Procedure

In modeling the general procedure followed include model development, model calibration, model verification and model application (Amegbey, 1997)

5.1.2. Model Development

This includes the development of ones own model or the use of existing model

For this study existing models were used. Seven Blast Vibration Predictor Equations were considered.

5.1.3. Model Calibration

The Seven Predictor Equations were calibrated using the models in Experimental Test Shots. This led to the determination of site constants.

5.1.4. Model Verification

A set of Production data from Teberebie Village and Government Hill were applied. The predicted values were compared with the measured values in order to verify the models. Suitable Blast Predictor equations were chosen.

5.1.5. Model Application

Having calibrated and verified the Seven models, two equations were found suitable for the area and were therefore applied to various scenarios.

5.2. BLAST VIBRATION EQUATIONS CONSIDERED

Seven Blast Vibration Predictor Equations were considered in the development of the model. These are presented below (Singh and Vogt, 1998) as follows:

5.2.1. United States Bureau of Mines (USBM) equation

This Equation assumed cylindrical explosive geometry for long cylindrical charges and concluded that any linear dimension should be scaled with the square root of the charge weight. Blasts should be scaled to the equivalent distance or scaled distance, which is defined as the actual distance divided by the square root of the charge weight. The equation is of the following form:

$$\text{USBM: } v = K. (R/\sqrt{Q_{\max}})^{-B}$$

Where

v = Peak particle velocity (mm/s)

K, B Site constants to be determined by regression analysis

R = distance of the measuring transducer from the blasting face (m)

$Q_{\max}$ = maximum charge per delay (kg)

5.2.2. Ambraseys – Hendron (AMHEN) Equation

For spherical symmetry, the USBM investigators suggested that any linear dimension should be scaled to the cube root of the charge weight. Thus, a scaled distance is the actual distance divided by the cube root of the charge weight. Later investigators particularly have also obtained similar results assuming spherical charge. The following equation utilizes cylindrical charge symmetry and thus any linear dimension should be scaled with the cube root of the charge weight. The equation is of the form:

$$\text{AMHEN: } v = K. (R/Q_{\max}^{1/3})^{-B}$$

Where

v = Peak particle velocity (mm/s)

K, B Site constants to be determined by regression analysis

R = distance of the measuring transducer from the blasting face (m)

$Q_{\max}$ = maximum charge per delay (kg)

5.2.3. Langefors and Kihlstrom (LANKH) equation

The following relationship for various charging levels ($Q_{\max}/R^{3/2}$) is suggested to estimate the peak particle velocity.

The equation is as follows:

$$\text{LANKH: } v = K. [\sqrt{Q_{\max}/R^{3/2}}]^B$$

Where

v = Peak particle velocity (mm/s)

K, B Site constants to be determined by regression analysis

R = distance of the measuring transducer from the blasting face (m)

$Q_{\max}$ = maximum charge per delay (kg)

5.2.4. Indian Standard Institution (IS) equation

The empirical relationship suggested by Indian Standard Institution (1973) uses the concept in which blast is scaled to the equivalent distance or scaled distance, defined as the charge weight divided by cube root of the square of actual distance. The relation is expressed as:

$$\text{IS: } v = K \cdot (Q_{\max}/R^{2/3})^B$$

Where

v = Peak particle velocity (mm/s)

K, B Site constants to be determined by regression analysis

R = distance of the measuring transducer from the blasting face (m)

$Q_{\max}$ = maximum charge per delay (kg)

5.2.5. General Type empirical (GEN) Equation

Davies et al., (1964); Attewell (1964); Birch and Chaffer (1983); Deamen et al., (1983), considered no particular charge symmetry, using a general equation instead,

$$\text{GEN: } v = K \cdot R^{-B} \cdot Q_{\max}^A$$

Where,

K, B and A = empirical constant which can be determined by multiple regression analysis of two independent variables.

5.2.6. Ghosh-Daemen (GHDN) modifications

Numerous inelastic effects cause energy losses during energy propagation. The inelastic effect leads to a decrease in amplitude in addition to those due to geometrical spreading.

The propagation equation of USBM and AMHEN had been reformulated by incorporating the inelastic attenuation factor $e^{-\alpha R}$, where α is the inelastic attenuation coefficient. The modified equations are:

$$\text{GHDN1: } v = K \cdot (R/\sqrt{Q_{\max}})^{-B} \cdot e^{-\alpha R},$$

Where

v = Peak particle velocity (mm/s)

K, B α Site constants to be determined by regression analysis

R = distance of the measuring transducer from the blasting face (m)

$Q_{\max}$ = maximum charge per delay (kg)

$$\text{GHDN2: } v = K \cdot (R/Q_{\max}^{1/3})^{-B} e^{-\alpha R},$$

Where

v = Peak particle velocity (mm/s)

K, B α Site constants to be determined by regression analysis

R = distance of the measuring transducer from the blasting face (m)
 Q_{max} = maximum charge per delay (kg)

5.2.7.1. CMRI predictor equation

The predictor model development by Central Mining Research Institute (Pal Roy et al., 1993) assumes special significance because of its simplified form and the consideration of the zone of disturbance due to blasting. The equation is valid only in the zone of disturbance (i.e. when $Q_{max} > 0, v > 0$). At the boundary of this zone, and out of this boundary, v is obviously 0 everywhere. When seismic waves propagate through a rock mass, they encounter an increasing volume of rock mass, causing decrease in energy density. In the process of this diminishing energy due to geometrical spreading, numerous inelastic effects that also cause energy loss during wave propagation simultaneously affect them and subsequently the amplitude is decreased. This equation considers two distinct categories of parameter n and K , where,

- n is related to the category of parameters that are influenced by rock properties and geometrical discontinuities, and
- K is related to design parameters including charge weight, distance from the source, charge diameter, burden, spacing, sub-grade drilling, stemming length and delay interval.

The equation is of the form:

$$\text{CMRI: } v = n + K.(R/\sqrt{Q_{max}})^{-1}$$

In order to apply these equations in the computer they were written as follows using the USBM as an example and the same procedure was adopted in the case of the rest of the Equations. These are presented in appendix 3

$$\text{USBM: } V = K.(R/\sqrt{Q_{max}})^{-B} = K.R^{-B}.Q_{max}^{B/2} \dots\dots\dots(1)$$

Taking natural log on both sides of equation (1), we have

$$\ln V = \ln K - B \ln R + B/2 \ln Q$$

$$v = k - br + b/2q = k + b(q/2 - r)$$

where $v = \ln V$, $k = \ln K$, $b = B$, $r = \ln R$ and $q = \ln Q$

(NB: The above definition will be used in subsequent equations.)

A linear regression analysis on $\ln V$ and $(1/2 \ln Q - \ln R)$ will be used to find K and B .

5.3. DATA SOURCE FOR MODEL DEVELOPMENT

Production Blasts and Experimental Test Shots given in Chapter 4 were stored and samples taken for analysis. The results of the Test Shots conducted are presented in Table 4.3 and were used for the Data Analysis in the calibration of the models

Table 4:2 shows the number of blasts monitored at Teberebie Village and Government Hill as well as the number of sampled blasts used in this study.

5.4. DETERMINATION OF SITE CONSTANTS

In order to show how site constants were determined the USBM equation was used as an example. All constants for the various predictor equations were obtained using regression analysis.

The USBM equation

$$V = K(R\sqrt{Q_{\max}})^{-B}$$
$$= K R^{-B} Q_{\max}^{B/2} \dots\dots\dots(1)$$

K and B are constants, V peak particle velocity; Q is maximum charge/delay and R distance in meters.

Taking natural logarithm on both sides of the equation it was written as:

$$\ln V = \ln K - B \ln R + B/2 \ln Q$$
$$v = k - br + bq/2$$

When the above is factorized,

$$v = b(q/2 - r) + k \dots\dots\dots(2)$$

Where $v = \ln V$, $k = \ln K$, $r = \ln R$, $B = B$ and $q = \ln Q$

Equation (2) is a linear equation of the form

$$y = mx + C \dots\dots\dots(3)$$

C is a constant or intercept and m the slope of the curve or the gradient. From equations (2) and (3), k is equivalent to C and b equivalent to m. Hence a linear regression analysis of $\ln V$ and $(1/2 \ln Q - \ln R)$ were used to obtain K and B.

From the test blasts, which are tabulated in Table 4.3, the input data, Q, V and R were substituted in the USBM equation.

With the help of the regression analysis tool, (Data Analysis Command in Tools Menu) in Excel application K and B were determined as follows:

The intercept and $(1/2 \ln Q - \ln R)$ coefficients are the values for k and b respectively. For the test shot the intercept obtained is about 5.7 and 1.3 for the $(1/2 \ln Q - \ln R)$ coefficient. Hence $\ln K = 5.7$ or $K = \text{EXP}(5.7) = 294.9$ and $b = 1.3$

The USBM equation can therefore be written as $V = 294.9(R\sqrt{Q_{\max}})^{-1.3}$

In Appendix 4 the regression analysis procedure is shown. The same procedure was used to determine site constants for all other equations and presented in Appendix 4 - 9. The results are presented in Table 5.1

Table 5.1: Site constants for various predictor equations

Site Constants				
Equation	K	β	A	α
USBM	294.88	1.32	-	-
AMHEN	1564.85	1.36	-	-
LANKH	60.92	1.70	-	-
IS	0.08	1.65	-	-
GEN	0.00	-3.54	--18.79	--
GHDN1	0.44	-0.82		0.00190
GHDN2	0.02	-2.23		0.00440

Using the Site Constants obtained in Table 5.1 the Blast Predictor Equations may be written in the forms presented in Table 5.2

Table 5.2: Blast Predictor Equations

Equation	Blast Predictor Equations
USBM	$V=294.9R^{-1.31}Q^{0.66}$
AMHEN	$V =1564.85R^{1.335}Q^{0.6775}$
LANKH	$V =60.92R^{1.2764}Q^{0.85095}$
IS	$V =0.08R^{1.1010}Q^{1.6515}$
GEN	$V =0.00R^{-3.5368}Q^{-18.7901}$
GHDN1	$V =0.44R^{.058210}Q^{-.4105}e^{-0.001928R}$
GHDN2	$V =0.02R^{.2.2256}Q^{-0.741861}e^{-0.00443}$

5.4.1. Determination of Predicted Peak Particle Velocity and Correlation Coefficient

In order to verify the models, blast data from Government Hill in Table 5.3 were substituted and peak particle velocities calculated. The calculated peak particle velocities were then compared with the observed values. The results obtained using USBM equation are shown in column (6) of Table 5.3

Table 5.3: Government Hill-Blast Data

1	2	3	4		5	6
Date	Time	Location	Q_{max} (kg/delay)	Dist. (R) (m)	Observed (ppv)	Predicted (ppv)
12-Jan-95	14:59:43	Govt Hill	864	1150	0.38	2.37
4-Jan-95	13:57:52	Govt Hill	818.8	1200	0.43	0.70
7-Jan-95	14:02:24	Govt Hill	765	1350	0.32	1.77
10-Jan-95	14:15:09	Govt Hill	468.2	2150	0.4	2.17
1-Dec-93	14:04:18	Govt Hill	230.9	3500	0.22	0.28
4-Dec-93	14:02:27	Govt Hill	390	3900	0.17	0.28
5-Dec-93	18:19:02	Govt Hill	390	3900	0.32	0.23
27-Nov-93	13:59:39	Govt Hill	121.9	3950	0.17	0.13

Applying the Correlation function in Excel the correlation between observed (actual) and predicted (calculated) peak particle velocities were calculated. This gives an indication of how reliable the predicted values will be when the equation is used in subsequent blast designs.

The same procedure was followed using data from Teberebie Village. This was also done for all other predictor equations and the procedure illustrated in Appendix 11 – 24. The Coefficient of Correlation at Teberebie Village and Government Hill are shown in Table 5.4

Table 5.4: Site Coefficient of Correlation at Teberebie Village and Government Hill

LOCATION	EQUATION						
	USBM	AMHEN	LANKH	IS	GEN	GHDN1	GHDN2
Teberebie Village	0.89	0.89	0.87	0.69	-0.34	-0.58	-0.34
Government Hill	0.73	0.73	0.71	0.70	-0.55	-0.84	-0.76

From Table 5.4 it can be seen that USBM and AMHEN are the most suitable Blast Predictor Equations

CHAPTER SIX

DISCUSSIONS, OBSERVATIONS AND FINDINGS

6.1. DRILLING, BLASTING AND MONITORING

The research conducted confirms that earlier blasts between 1993 and 1995 indicated quite high peak particle velocities but has since improved considerably and the present values are considered safe. There has been consistent decrease in ground vibration, improvement in fragmentation, and overall mining costs and therefore greater efficiency over the years as indicated in Table 6.1

Table 6.1: Results of peak particle velocity (ppv) between 1994-1998

FROM	TO	LOCATION	MAX (ppv)	MIN (ppv)
6-Jan-95	21-Mar-98	Teberebie village	193.63	0.21
25-Apr-96	17-May-97	Government Hill	1.44	0.17
26-Sep-94	21-Apr-97	Mantraim Ridge	17.56	0.25
6-Oct-94	24-Oct-97	Awunaben Ridge	32.00	0.06
17-Jan-98	7-Feb-98	Mine office	8.72	0.68

Various types of explosives were used for blasting in the area throughout the life of the mine with due consideration to the complex nature of type of rock mass in the concession until bulk emulsion products mixed with ammonium nitrate prills were finally introduced due to high rate of ground water in the drill holes. This product provides solutions to the problems encountered earlier.

TGL practiced electric initiation until 1991 when it stopped and introduced non-electric system to provide safe user-friendly solutions that are completely reliable. It continued to use the exploder to initiate electrically instead of the capped fuse for obvious reasons.

Initially, the row on row firing method was used i.e. all the holes on a particular row are set off at definite timing sequence. This method was later improved upon by introducing the echelon i.e. meaning shooting row on row in diagonal sequence. Comparatively, the later system provided better fragmentation and reduced air blast, fly-rock and ground vibration but in order to further improve on the back-break the last row is now always given a longer delay period from the rest of the rows i.e. between 12-16 m/s, for every 1m of burden distance. 65m/s –100m/s

Despite the proper observations of blasting rules by TGL and religiously adhering to posting shot locations and blasting times daily at the Mine Office, the surrounding villages however, cannot have access to this information due to proximity problems. Efforts should be made to inform them.

6.2. GROUND VIBRATION PREDICTOR EQUATIONS

Seven Predictor Equations were considered and the most suitable Blast Predictor models for calculation of charge per delay for safe and efficient blasting devoid of possible damages and disturbances to the community in the District are USBM and AMHEN.

6.2.1. Site Constants

The rocks at TGL are softer and more weathered near surface. They have lower propagation velocity of the vibration wave resulting in the vibration being dampened faster with lower vibration structures at longer distances from the blasts. When geological characteristics of the underlying rocks change to more homogenous rock it results in increasing the ground vibrations. (Langefors and Kihlstrom, 1963)

From the foregoing it is observed that the constants are influenced by geological environment and also have their own ground vibration characteristics, which affect the propagation of the vibration wave.

The low coefficient of correlation recorded may be due to probable distortions in geological formations and inaccuracies in distance measurements during monitoring.

6.3. REDUCTION IN PEAK PARTICLE VELOCITY WITH DISTANCE

In Tables 5.4 it is observed that peak particle velocity reduces considerably with increasing distances from the blasting site. This thus confirms the Central Mining Research Institute's (Pal Roy et al., 1993) affirmation that when seismic wave propagates through a rock mass, it encounters an increasing volume of rock mass, causing decrease in energy density. In the process of this diminishing energy due to geometrical spreading, numerous inelastic effects that also cause energy loss during wave propagation simultaneously affect them and subsequently the amplitude is decreased. At the boundary of this zone, and out of this boundary, ppv is obviously 0 everywhere when the site constants are applied.

Using similar assumptions, it can safely be concluded that TGL blasts at the site will not cause damage to property outside the concession.

It is also observed that for a blast to register a peak particle velocity (ppv) of say 5mm/s, several thousands of kilograms of charge per delay would be required.

In practice, however, these values are far above the quantity of charge currently used in carrying out blasts at TGL mine. Hence structural damages in any form cannot take place in these residential areas from any blast operations carried out at TGL. Air-blast probably might be the cause of the complaints.

6.4. NOISE, VIBRATION AND AIR-BLAST DUE TO BLASTING

Noise is observed to last only a few seconds (140dB(A) and 79.6dB(A)) (Down and Stocks 1978) and can be tolerated if people are made aware of the time of blasts. The impact of noise, vibration and air-blast on both human and animals can be quite pronounced and therefore it is agreed with the respondents of the questionnaire that it can cause nuisance. The unexpected noise, vibration and air-blast can adversely affect their sleep pattern and their social life at where mining operations adjoin residential areas such as the Teberebie Village, Govt. Hill, etc. Though the people feel the ground vibrations at very low levels, they often over estimate the risk of damage to building and themselves and this tends to colour their perception of the impacts.

The residents thought to be outside the area of blasting are also likely to be affected by noise, vibration and air-blast problems during temperature inversions periods (Andrew Geraghy, 1998).

6.5. SOCIAL ISSUES

Through the questionnaire administration it is found out that TGL must maintain good neighbour status with the community by responding to concerns about aspects of the TGL operations.

Greater communication is essential with the inhabitants at all times. The Company needs to explain its policies pertaining to mining activities that are inimical to the people.

Dialogue may lead to creative solutions to address these blasting problems for example, where relationships are unlikely to be harmonious. The direct action taken because of environmental issues by the pressure groups at TGL was the result of lack of trust and misunderstanding and could be averted if proper dialogue was entered into at the appropriate time.

It is also observed that the inhabitants are fulfilling a vital role by calling attention to commercial abuse or injustice that might otherwise be ignored.

The negative view held by the people especially the Chiefs, opinion leaders etc. can be altered by such visits where factual information could be ascertained and these can have substantial potential to change people's negative attitude towards mining.

Public perceptions of a risk by blasting, in the areas studied, however are probably frequently out of phase with real risks.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.1. CONCLUSIONS

The present systems of blast and monitoring at TGL have been studied; site constants have been determined. The most suitable Blast Predictor Equations, USBM and AMHEN for the calculation of charge per delay for safe and efficient blasting devoid of possible damages and disturbance to the community in the District have been chosen.

With consideration to the above, TGL may develop a blasting procedure that will be both productive and environmentally acceptable.

Public perception of risk due to blasting had been identified as out of face with real risks.

Research conducted confirms the resulting improvement through monitoring since earlier blasts between 1993 and 1994 showed that the high peak particle velocity experienced has since improved considerably and the present values are considered safe.

Monitored results of TGL are valid and consistent

7.1.1. Teberebie Village, Government Hill and Surrounding Districts

Structures within the working radius, where all the offices are, including Teberebie village are safe.

Due to the protocol and performance displayed by TGL there has not been any damage to Engineering Office building (or glass) and the old magazine, which are the closest structures to the pit, and there are no human injuries recorded due to fly rocks.

7.2. RECOMMENDATIONS

A pre-blast inspection and investigation is necessary to set up Baseline information prior to start of the blast in the area to avert any future complaints by the inhabitants.

Due to perception of the inhabitants it is necessary that a lot of education be mounted to explain why it is important to blast and the possible merits and demerits of the process.

Since the people in the concession are much more tolerant if the exposure time is small, they must be properly informed of why they must be exposed to the vibrations, how the vibrations will affect them and their property and the exact time when they will be exposed to the vibration.

The TGL Geology department should consider drawing up geological maps to assist in the positioning and design of the blast patterns (reducing the dissection' of the ore zones) that will facilitate in the prediction of any structural shifts in the ore body and thus provide the final back-wall design.

Local Geological settings or configuration surrounding mining is determinant in the propagation of blasting vibrations; the dissipation of the energy vary with the geological setting and fault networks which will channel the energy in preferential directions. Consequently a proper evaluation is necessary.

Blast at regular times where possible and publicize the timing of blast to reduce the element of surprise and it is necessary that Ghanaian Australian Goldfields, Teberebie Goldfields Limited and Goldfields Ghana Limited blast timing is co-ordinated.

Settle promptly any legitimate damage claims.

The Chamber of Mines and Environmental Protection Agency should sponsor research into similar work to establish ground vibration limits in Ghana Mining and all quarry areas.

Mireku-Gyimah, D. (1997) "Operations Research in Mining, (TME 503) Tarkwa (Overview of Operations Research), Lecture 1", unpublished report, pp 1-12.

Oloffson, S. O. (1988) "Applied Explosives Technology for Construction and Mining, ARLA, NORA Boktryckeri AB, Applex, Sweden", pp 201-205.

Singh, P. M. and Vogt, W. (1988), ", Ground Vibration Prediction for safe and efficient Blasting, Central Mining Research Institute", Erzmetall 51 Nr. 10, pp 677-683.

Siskind, E. D. and Stag, M. S. (1987) "Blast Vibration Measurement near Structures" White Pine, M1: USBM, RI 7751, Chicago, pp 155-161.

REFERENCES

- Agbeno, S (1999)** "Explosives and Rock Fragmentation (Surface Blasting) TME 511", unpublished report, pp 337-372.
- Amegbey, N. (1998)** "Environmental Engineering in Mining, TME 512 Tarkwa", unpublished report, pp 41-46.
- Annon, (1990).** "Environmental Impact Assessment for Teberebie Goldfields Limited", Jay Minerals Limited, unpublished report, pp 6-10.
- Annon, (1993)** "Environmental Assessment of the Proposed Expansion at Teberebie Goldfields Limited, Tarkwa, Ghana", Cremer and Warner Limited, March, unpublished report, pp 35-45.
- Annon, (1995)** "Environmental Impact Statement for the Phase III, Expansion at Teberebie Goldfields", SGS Environment, November, unpublished report, pp 32-43.
- Annon, (1996)** "Social Audit for Teberebie Goldfields Limited", SGS Environment, Aug, unpublished report, pp 1-9.
- Annon, (1998)** "Environmental Audit for Teberebie Goldfields Limited", SGS, Environment, March, unpublished report, pp 7-14.
- Annon, (1998).** "Environmental Audit for Teberebie Goldfields Limited" SGS, Environment, December, unpublished report, pp 15-23.
- Duvall, W. I. and Fogelson, D. E. (1962),** "Review of Criteria for Estimating Damage to Residencies from Blasting Vibrations," BuMines Report of Investigations, No. 5968 pp 1-8.
- Konya, C. J. (1996a)** "Comparison of Different Blast Design Methods", E&MJ (Sept.) Robert J. M. Wyllie, Associate Publisher and Editor, Chicago, Illinois 60606, U.S.A. pp 80-85.
- Konya, C. J. (1996b)** "Trouble Shooting Problem Blasts", E&MJ January, Robert J. M. Wyllie, Associate Publisher and Editor, Chicago, Illinois 60606, U.S.A. pp 27.
- Konya, C. J. (1996c)** "Blasting Review & Maintenance Program", E&MJ November, Robert J. M. Wyllie, Associate Publisher and Editor, Chicago, Illinois 60606, U.S.A. p 47
- Mayes, W. H. and Edge, P. M. (1964)** "Effects of sonic boom and other shock waves on buildings," Minerals Research and Standards, pp 588-593.

APPENDIX 1

QUESTIONNAIRE TO FIND OUT THE EFFECTS OF BLASTING ON RESIDENTS AROUND THE MINING COMPANIES

1. Sex: male/female
2. Age.
3. Occupation
4. Residence (where you are currently staying).
5. Number of years you have stayed at your place.
6. Have you experienced blasting from any mining company before, especially TGL?
Yes / No
7. If yes, then what do you think are some of the effects of blasting at your area of residence?
8. Have you experienced blasting for five (5) years? Yes / No
9. If yes, how do you compare the effects of blasting at your area during the five years and the effects after the five years stay at your area?
10. Do you think the effects have changed from good to bad or vice versa?
11. Can you please state some of the changes?
12. If negative effects are being experienced, have you ever complained?
13. What authority have you complained to?
14. What has been the response from the authority concern?
15. Have they addressed the problem? Yes / No
16. If yes, how have they done that?
17. Are you satisfied with the response so far? Yes / No
18. If no, what do you think the mining company concerned can do to solve the problem?
19. Why do you think the mining companies' blast at all?
20. How is the vibration like?

APPENDIX 2
SHOWING INPUT BLASTS USED IN THE MODELLING

(A) TEST SHOT,

Date	Time	Location	V (mm/s)	Q (kg/delay)	R (m)
28-Jan-99	13:56:49	Magazine	10.4	1050	350
30-Jan-99	15:42:22	GH	1.03	720	1650
29-Jan-99	13:57:00	Magazine	5.52	1050	1000
30-Jan-99	15:42:35	GH	1.08	720	1800

(B) GOVERNMENT HILL -PRODUCTION DATA

27-Nov-93	13:59:39	Govt Hill	0.17	121.9	3950
01-Dec-93	14:04:18	Govt Hill	0.22	230.9	3500
04-Dec-93	14:02:27	Govt Hill	0.17	390	3900
05-Dec-93	18:19:02	Govt Hill	0.32	390	3900
04-Jan-95	13:57:52	Govt Hill	0.43	818.8	1200
07-Jan-95	14:02:24	Govt Hill	0.32	765	1350
10-Jan-95	14:15:09	Govt Hill	0.4	468.2	2150
12-Jan-95	14:59:43	Govt Hill	0.38	864	1150

(C) TEBEREBIE VILLAGE-PRODUCTION DATA

27-Nov-93	13:59:39	TV	0.17	121.9	3950
29-Nov-93	13:59:43	TV	0.48	141.9	950
02-Dec-93	14:06:11	TV	0.7	76.6	350
11-Dec-93	14:00:49	TV	2.14	188.5	400.3
07-Jan-94	13:59:46	TV	3.7	576.5	400.1
15-Jan-94	14:30:23	TV	3.78	595.8	350
17-Jan-94	13:58:26	TV	3.06	583	550
17-Jan-94	14:03:58	TV	0.43	224	1500
23-Jan-94	12:44:29	TV	3.51	582	550
24-Jan-94	14:07:55	TV	3.13	375.7	400.8
25-Jan-94	14:03:18	TV	3.06	487.3	400.8
29-Jan-94	14:02:06	TV	4.3	1018.7	400
06-Jan-95	16:29:30	TV	3.19	716	450
09-Jan-95	14:00:20	TV	0.64	495	1050
09-Jan-95	17:02:25	TV	1.54	661.1	1050
11-Jan-95	15:41:56	TV	0.54	700	1150
11-Jan-95	14:07:55	TV	0.59	720	1150
13-Jan-95	15:03:15	TV	0.62	720	1150
06-Jun-95	16:29:30	TV	3.19	716	450
09-Jun-95	17:02:25	TV	1.54	661.1	1050
12-Jun-95	15:58:49	TV	2.62	460	600
27-Jul-95	16:00:40	TV	1.3	552	900
03-Jan-96	16:02:10	TV	3.18	660	700
04-Apr-96	16:55:51	TV	2.32	1186.4	600
10-May-96	14:02:04	TV	0.73	450	1650
20-May-96	17:01:37	TV	2.11	450	600
30-May-96	14:00:36	TV	2.65	720	600
01-Jun-96	14:07:13	TV	3.41	630	600
25-Apr-98	18:02:00	TV	1.44	710	800

APPENDIX 3: EQUATIONS RE-WRITTEN TAKING NATURAL LOG ON BOTH SIDES

AMHEN $V = K(R/Q_{\max}^{1/3}) = K.R^{-B} . Q_{\max}^{B/3} \dots\dots\dots(2)$

Taking natural log on both sides of eqn. (2), we have

$$\ln V = \ln K - B \ln R + B/3 \ln Q$$

$$V = k - br + b/3q = k + b(q/3 - r)$$

A linear regression analysis on $\ln V$ and $(1/3 \ln Q - \ln R)$ was used to find K and B

LANKH $V = K [\sqrt{Q_{\max}/R^{3/2}}]^B = K.R^{-3/4B} . Q_{\max}^{B/2} \dots\dots\dots(3)$

Taking natural log on both sides of eqn. (3), we have

$$\ln V = \ln K - 3/4 B \ln R + B/2 \ln Q$$

$$V = k - 3/4 br + b/2q = k + b(q/2 - 3r/4)$$

A linear regression analysis on $\ln V$ and $(1/2 \ln Q - 3/4 \ln R)$ was used to find K and B

IS $V = K (Q_{\max} R^{2/3})^B R^{-B} = K.R^{-2/3B} . Q_{\max}^B \dots\dots\dots(4)$

Taking natural log on both sides of eqn. (4), we have

$$\ln V = \ln K - 2/3 B \ln R + B \ln Q$$

$$V = k - 2/3 br + bq = k + b(q - 2/3 r)$$

A linear regression analysis on $\ln V$ and $(\ln Q - 2/3 \ln R)$ was used to find K and B

GEN $V = K Q_{\max}^A R^{-B} \dots\dots\dots(5)$

Taking natural log on both sides of eqn. (4), we have

$$\ln V = \ln K - B \ln R + A \ln Q$$

$$V = k - br + aq \quad \text{Where } a = A$$

Multiple regression analysis on R, $\ln V$ and $(1/2 \ln Q - \ln R)$ was used to find K, B and a

GHDN1 $V = K (R/Q_{\max})^{-B} . e^{-\alpha R} = K.R^{-B} . Q_{\max}^{B/2} . -e^{\alpha R} \dots\dots\dots(6)$

Taking natural log on both sides of eqn. (7), we have

$$\ln V = \ln K - B/2 \ln Q - B \ln R - \alpha R$$

$$V = k + b/2q - br - \alpha R$$

$$bR = k/a + (b/2a)q - (b/a)r - v/a$$

$$= k/a + b/a(1/2q - r) - (1/a)v$$

Multiple regression analysis on R, $\ln V$ and $(1/2 \ln Q - \ln R)$ was used to find K, B and a

GHDN2 $V = K (R/Q_{\max}^{1/3})^{-B} . e^{-\alpha R} = K.R^{-B} . Q_{\max}^{B/3} . -e^{\alpha R} \dots\dots\dots(7)$

Taking natural log on both sides of eqn. (7), we have

$$\ln V = \ln K + B/3 \ln Q - B \ln R - \alpha R$$

$$V = k + b/3q - br - \alpha R$$

$$bR = k/a + (b/3a)q - (b/a)r - v/a$$

$$= k/a + b/a(q/3 - r) - (1/a)v$$

Multiple regression analysis on R, $\ln V$ and $(1/2 \ln Q - \ln R)$ was used to find K, B and a

APPENDIX 4 TEST SHOT USING USBM EQUATION TO DETERMINE SITE CONSTANTS

USBM

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.95
R Square	0.90
Adjusted R Square	0.86
Standard Error	0.44
Observations	4.00

ANOVA

	df	SS	MS	F	Significance F
Regression	1.0000	3.6967	3.6967	18.8059	0.0493
Residual	2.0000	0.3931	0.1966		
Total	3.0000	4.0899			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	5.6866	1.0944	5.1963	0.0351	0.9779	10.3952	0.9779	10.3952
(1/2lnQ-lnR)	1.3152	0.3033	4.3366	0.0493	0.0103	2.6202	0.0103	2.6202

From the summary output above the constants can be tabulated and the equation written as follows:

K	B	Equation
294.8789	1.3152	$V=294.9R^{-1.31}Q^{0.66}$

Observed V	Predicted V	Correlation
10.40	12.89	0.95
1.03	1.31	
5.52	3.24	
1.08	1.17	

APPENDIX 5 TEST SHOT USING AMHEN EQUATION TO DETERMINE SITE CONSTANTS

AMHEN SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.943466
R Square	0.890128
Adjusted R Squar	0.835192
Standard Error	0.474004
Observations	4

ANOVA

	df	SS	MS	F	gnificance F
Regression	1	3.6405	3.6405	16.20305	0.056534
Residual	2	0.44936	0.22468		
Total	3	4.08986			

	Coefficients	andard Err	t Stat	P-value	Lower 95%	pper 95%	ower 95.0%	Upper 95.0%
Intercept	7.355546	1.586964	4.634979	0.043531	0.527386	14.1837	0.527386	14.1837069
(1/3lnQ-lnR)	1.355016	0.336625	4.025301	0.056534	-0.09336	2.8034	-0.09336	2.80339564

From the summary output above the constants can be tabulated and the equation written as follows:

K	B	Equation
1564.8516	1.3550	$V=1564.8516R^{1.3550}Q^{0.6775}$

Observed V	Predicted V	Correlation
10.40	12.94	0.94
1.03	1.33	
5.52	3.12	
1.08	1.19	

APPENDIX 6
TEST SHOT USING LANKH EQUATION TO DETERMINE SITE CONSTANTS

LANKH
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.957021
R Square	0.915888
Adjusted R Squ	0.873833
Standard Error	0.414731
Observations	4

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	3.7458556	3.745856	21.77795	0.042979
Residual	2	0.3440044	0.172002		
Total	3	4.0898601			

	Coefficient	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	4.109599	0.6898497	5.957239	0.02704	1.141414	7.07779	1.14141	7.07778504
(1/2lnQ-3/4lnR)	1.701885	0.3646882	4.666685	0.042979	0.132757	3.27101	0.13276	3.2710128

K	B	Equation
60.9223	1.7019	$V=60.9223R^{1.2764}Q^{0.85095}$

Observed V	Predicted V	Correlation
10.40	12.83	0.95
1.03	1.29	
5.52	3.36	
1.08	1.15	

APPENDIX 7 TEST SHOT USING IS EQUATION TO DETERMINE SITE CONSTANTS

IS
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.97823
R Square	0.95693
Adjusted R Square	0.9354
Standard Error	0.29677
Observations	4

ANOVA

	df	SS	MS	F	Significance F
Regression	1	3.9137127	3.913713	44.4368	0.0217716
Residual	2	0.1761474	0.088074		
Total	3	4.0898601			

	Coefficient	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-2.52196	0.5544411	-4.54865	0.045088	-4.907526	-0.13639	-4.90753	-0.13638727
(lnQ-2/3lnR)	1.65152	0.2477498	6.666093	0.021772	0.5855411	2.717505	0.585541	2.717505159

K	B	Equation
0.0803	1.6515	$V = 0.0803R^{1.1010}Q^{1.6515}$

Observed V	Predicted V	Correlation
10.40	12.39	0.97
1.03	1.21	
5.52	3.90	
1.08	1.10	

APPENDIX 8

TEST SHOT USING GEN EQUATION TO DETERMINE SITE CONSTANTS

GEN

SUMMARY OUTPUT

Regression Statistics	
Multiple R	1.00
R Square	1.00
Adjusted R Square	1.00
Standard Error	0.07
Observations	4.00

ANOVA

	df	SS	MS	F	Significance F
Regression	2.0000	4.0849	2.0425	412.1036	0.0348
Residual	1.0000	0.0050	0.0050		
Total	3.0000	4.0899			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-18.7901	2.7712	-6.7806	0.0932	-54.0008	16.4205	-54.0008	16.4205
lnQ (kg/delay)	3.5386	0.3264	10.8406	0.0586	-0.6089	7.6861	-0.6089	7.6861
lnR (m)	-0.5955	0.0945	-6.3012	0.1002	-1.7964	0.6053	-1.7964	0.6053

From the summary output above the constants can be tabulated and the equation written as follows:

K	B	A	Equation	Observed V	Predicted V	Correlation
0.0000	-3.5386	-18.7901	$V=6.911E-09R^{3.5386}Q^{-18.7901}$	10.40	0.00	-0.87
				1.03	0.00	
				5.52	0.00	
				1.08	0.00	

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APPENDIX 9

TEST SHOT USING GHDN1 EQUATION TO DETERMINE SITE CONSTANTS

GHDN1
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9974
R Square	0.9949
Adjusted R Squ	0.9847
Standard Error	82.285
Observations	4

ANOVA					
	df	SS	MS	F	Significance F
Regression	2	1318229	659114.6	97.34669	0.071484508
Residual	1	6770.796	6770.796		
Total	3	1325000			

	Coefficient	Standard Err	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-425.9	773.412	-0.55064	0.679567	-10252.9611	9401.2	-10252.96106	9401.21698
(1/2lnQ-lnR)	-518.7	181.5497	-2.85718	0.214331	-2825.51843	1788.1	-2825.518428	1788.07702
lnV	-199.2	131.2334	-1.51805	0.370828	-1866.6897	1468.3	-1866.6897	1468.25293

K	B	α	Equation	Observed V	Predicted V	Correlation
4.3999E-01	-0.8210	0.001928	$V=4.3999E-01R^{0.8210}Q^{-.4105}e^{-0.001928R}$	10.40	1.58	0.99
				1.03	0.54	
				5.52	1.07	
				1.08	0.43	

APPENDIX 10

TEST SHOT USING GHDN2 EQUATION TO DETERMINE SITE CONSTANTS

GHDN2 SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.997328
R Square	0.994663
Adjusted R	0.983988
Standard Error	84.09453
Observations	4

ANOVA

	df	SS	MS	F	Significance F
Regression	2	1317928	658964	93.18075	0.073057
Residual	1	7071.89	7071.89		
Total	3	1325000			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-907.066	964.7502	-0.94021	0.519613	-13165.33	11351.19	-13165	11351.1944
(1/3)lnQ-lnR	-502.334	180.1726	-2.78807	0.219238	-2791.634	1786.965	-2791.6	1786.96541
lnV	-225.709	125.45	-1.7992	0.32295	-1819.696	1368.277	-1819.7	1368.27726

K	B	α	Equation	Observed V	Predicted V	Correlation
1.7976E-02	-2.2256	0.004430	$1.7976E-02 R^{2.2256} Q^{-0.741861} e^{-0.0044}$	10.40	10.05	1.00
				1.03	1.32	
				5.52	5.83	
				1.08	0.82	

APPENDIX 11

SITE CONSTANTS AND PRODUCTION DATA USED TO DETERMINE COEFFICIENT OF CORRELATION AT TEBEREBIE VILLAGE USING USBM EQUATIO

USBM -TV
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.95
R Square	0.90
Adjusted R Square	0.86
Standard Error	0.44
Observations	4.00

ANOVA

	df	SS	MS	F	Significance F
Regression	1.0000	3.6967	3.6967	18.8059	0.0493
Residual	2.0000	0.3931	0.1966		
Total	3.0000	4.0899			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	5.6866	1.0944	5.1963	0.0351	0.9779	10.3952	0.9779	10.3952
(1/2lnQ-lnR)	1.3152	0.3033	4.3366	0.0493	0.0103	2.6202	0.0103	2.6202

From the summary output above the constants can be tabulated and the equation written as follows:

K	B	Equation	Observed V	Predicted V	Correlation
294.8789	1.3152	V=294.9R-1.31Q0.66	0.17	0.13	0.89
			0.48	0.93	
			0.70	2.31	
			2.14	3.49	
			3.70	7.29	
			3.78	8.88	
			3.06	4.83	
			0.43	0.69	
			3.51	4.83	
			3.13	5.49	
			3.06	6.51	
			4.30	10.60	
			3.19	7.20	
			0.64	1.85	
			1.54	2.24	
			0.54	2.07	
			0.59	2.10	
			0.62	2.10	
			3.19	7.20	
			1.54	2.24	
			2.62	3.69	
			1.30	2.44	
			3.18	3.82	
			2.32	6.88	
			0.73	0.96	
			2.11	3.64	
			2.65	4.95	
			3.41	4.54	
			1.44	3.36	

N

APPENDIX 12

SITE CONSTANTS AND PRODUCTION DATA USED TO DETERMINE COEFFICIENT OF CORRELATION AT TEBEREBIE VILLAGE USING AMHEN EQUATION

AMHEN -TV
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.943466
R Square	0.890128
Adjusted R S	0.835192
Standard Err	0.474004
Observations	4

ANOVA

	df	SS	MS	F	Significance F
Regression	1	3.6405	3.6405	16.20305	0.056534
Residual	2	0.44936	0.22468		
Total	3	4.08986			

	Coefficients	Standard Err	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	7.355546	1.586964	4.634979	0.043531	0.527386	14.1837	0.527386	14.1837069
(1/3lnQ-lnR)	1.355016	0.336625	4.025301	0.056534	-0.09336	2.8034	-0.09336	2.80339564

From the summary output above the constants can be tabulated and the equation written as follows:

K	B	Equation
1564.8516	1.3550	$V=1564.8516R^{1.3550}Q^{0.6775}$

Observed	Predicted V	Correlation
0.17	0.54	0.89
0.48	4.15	
0.70	10.56	
2.14	16.21	
3.70	34.59	
3.78	42.40	
3.06	22.65	
0.43	3.04	
3.51	22.62	
3.13	25.82	
3.06	30.79	
4.30	50.89	
3.19	34.16	
0.64	8.44	
1.54	10.27	
0.54	9.44	
0.59	9.62	
0.62	9.62	
3.19	34.16	
1.54	10.27	
2.62	17.14	
1.30	11.20	
3.18	17.77	
2.32	32.57	
0.73	4.29	
2.11	16.89	
2.65	23.22	
3.41	21.21	
1.44	15.58	

APPENDIX 13
SITE CONSTANTS AND PRODUCTION DATA USED TO DETERMINE COEFFICIENT OF
CORRELATION AT TEBEREBIE VILLAGE USING LANKH EQUATION

LANKH -TV
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.957021
R Square	0.915888
Adjusted R Square	0.873833
Standard Error	0.414731
Observations	4

ANOVA

	df	SS	MS	F	gnificance F
Regression	1	3.7458556	3.745856	21.77795	0.042979
Residual	2	0.3440044	0.172002		
Total	3	4.0898601			

	Coefficients	standard Err	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	4.109599	0.6898497	5.957239	0.02704	1.141414	7.07779	1.14141	7.07778504
(1/2lnQ-3/4lnR)	1.701885	0.3646882	4.666685	0.042979	0.132757	3.27101	0.13276	3.2710128

K	B	Equation
60.9223	1.7019	$V=60.9223R^{1.2764}Q^{0.85095}$

Observed	Predicted	Correlation
0.17	0.00	0.87
0.48	0.04	
0.70	0.11	
2.14	0.20	
3.70	0.51	
3.78	0.66	
3.06	0.30	
0.43	0.02	
3.51	0.30	
3.13	0.35	
3.06	0.44	
4.30	0.82	
3.19	0.50	
0.64	0.09	
1.54	0.11	
0.54	0.10	
0.59	0.10	
0.62	0.10	
3.19	0.50	
1.54	0.11	
2.62	0.21	
1.30	0.12	
3.18	0.22	
2.32	0.47	
0.73	0.04	
2.11	0.21	
2.65	0.31	
3.41	0.27	
1.44	0.19	

APPENDIX 14 SITE CONSTANTS AND PRODUCTION DATA USED TO DETERMINE COEFFICIENT OF CORRELATION AT TEBEREBIE VILLAGE USING IS EQUATION

IS -TV
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.97823
R Square	0.95693
Adjusted R Square	0.9354
Standard Error	0.29677
Observations	4

ANOVA

	df	SS	MS	F	Significance F
Regression	1	3.9137127	3.913713	44.4368	0.0217716
Residual	2	0.1761474	0.088074		
Total	3	4.0898601			

	Coefficient	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-2.52196	0.5544411	-4.54865	0.045088	-4.907526	-0.13638727	-4.90753	-0.13638727
(lnQ-2/3lnR)	1.65152	0.2477498	6.666093	0.021772	0.5855411	2.717505159	0.585541	2.717505159

K	B	Equation
0.0803	1.6515	$V = .0803R^{1.1010}Q^{1.6515}$

Observed V	Predicted V	Correlation
0.17	0.02	0.69
0.48	0.15	
0.70	0.16	
2.14	0.63	
3.70	3.97	
3.78	4.86	
3.06	2.85	
0.43	0.19	
3.51	2.84	
3.13	1.96	
3.06	3.00	
4.30	10.18	
3.19	4.99	
0.64	1.07	
1.54	1.72	
0.54	1.71	
0.59	1.79	
0.62	1.79	
3.19	4.99	
1.54	1.72	
2.62	1.75	
1.30	1.52	
3.18	2.68	
2.32	8.38	
0.73	0.55	
2.11	1.69	
2.65	3.67	
3.41	2.95	
1.44	2.61	

APPENDIX 15
SITE CONSTANTS AND PRODUCTION DATA USED TO DETERMINE COEFFICIENT OF
CORRELATION AT TEBEREBIE VILLAGE USING GHND1 EQUATION

GHDN1 -TV
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9974
R Square	0.9949
Adjusted R Square	0.9847
Standard Error	82.285
Observations	4

ANOVA

	df	SS	MS	F	Significance F
Regression	2	1318229	659114.6	97.34669	0.071484508
Residual	1	6770.796	6770.796		
Total	3	1325000			

	Coefficient	Standard Err.	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-425.9	773.412	-0.55064	0.679567	-10252.9611	9401.2	-10252.96106	9401.216981
(1/2lnQ-lnR)	-518.7	181.5497	-2.85718	0.214331	-2825.51843	1788.1	-2825.518428	1788.077018
lnV	-199.2	131.2334	-1.51805	0.370828	-1866.6897	1468.3	-1866.6897	1468.252931

K	B	Q	Equation	Observed V	Predicted V	Correlation
4.3999E-01	-0.8210	0.001928	$V=4.3999E-01R^{0.8210}Q^{-0.4105}e^{-0.001928R}$	0.17	54.95	-0.58
				0.48	16.02	
				0.70	9.09	
				2.14	7.01	
				3.70	4.43	
				3.78	3.92	
				3.06	5.73	
				0.43	19.33	
				3.51	5.73	
				3.13	5.29	
				3.06	4.75	
				4.30	3.51	
				3.19	4.46	
				0.64	10.42	
				1.54	9.25	
				0.54	9.74	
				0.59	9.62	
				0.62	9.62	
				3.19	4.46	
				1.54	9.25	
				2.62	6.78	
				1.30	8.78	
				3.18	6.64	
				2.32	4.60	
				0.73	15.70	
				2.11	6.84	
				2.65	5.64	
				3.41	5.96	
				1.44	7.19	

APPENDIX 16

SITE CONSTANTS AND PRODUCTION DATA USED TO DETERMINE COEFFICIENT OF
CORRELATION AT TEBEREBIE VILLAGE USING GHND2 EQUATION
GHND2 -TV
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.997327792
R Square	0.994662724
Adjusted R Squ	0.983988173
Standard Error	84.09453297
Observations	4

ANOVA					
	df	SS	MS	F	Significance F
Regression	2	1317928.11	658964.0548	93.18075	0.073057
Residual	1	7071.890476	7071.890476		
Total	3	1325000			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-907.0660274	964.7501503	-0.94020823	0.519613	-13165.33	11351.19	-13165.326	11351.19
(1/3lnQ-lnR)	-502.3341275	180.1725529	-2.78807243	0.219238	-2791.634	1786.965	-2791.6337	1786.965
lnV	-225.7091566	125.4499888	-1.79919631	0.32295	-1819.696	1368.277	-1819.6956	1368.277

K	B	α	Equation	Observed V	Predicted V	Correlation
1.7976E-02	-2.2256	0.004430	$V=1.7976E-02R^{2.2256}Q^{-0.741861}e^{-0.004430}$	0.17	8667.99	-0.34
				0.48	307.00	
				0.70	66.06	
				2.14	32.70	
				3.70	9.42	
				3.78	6.74	
				3.06	18.88	
				0.43	510.50	
				3.51	18.91	
				3.13	15.22	
				3.06	11.40	
				4.30	4.99	
				3.19	9.61	
				0.64	95.51	
				1.54	69.22	
				0.54	79.53	
				0.59	77.07	
				0.62	77.07	
				3.19	9.61	
				1.54	69.22	
				2.62	29.83	
				1.30	60.03	
				3.18	28.13	
				2.32	10.39	
				0.73	290.39	
				2.11	30.56	
				2.65	18.12	
				3.41	21.02	

APPENDIX 17

SITE CONSTANTS AND PRODUCTION DATA USED TO DETERMINE COEFFICIENT OF CORRELATION AT TEBEREBIE VILLAGE USING GEN EQUATION

GEN -TV

SUMMARY OUTPUT

Regression Statistics	
Multiple R	1.00
R Square	1.00
Adjusted R Square	1.00
Standard Error	0.07
Observations	4.00

ANOVA					
	df	SS	MS	F	Significance F
Regression	2.0000	4.0849	2.0425	412.1036	0.0348
Residual	1.0000	0.0050	0.0050		
Total	3.0000	4.0899			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-18.7901	2.7712	-6.7806	0.0932	-54.0008	16.4205	-54.0008	16.4205
lnQ (kg/delay)	3.5386	0.3264	10.8406	0.0586	-0.6089	7.6861	-0.6089	7.6861
lnR (m)	-0.5955	0.0945	-6.3012	0.1002	-1.7964	0.6053	-1.7964	0.6053

From the summary output above the constants can be tabulated and the equation written as follows:

K	B	A	Equation	Observed V	Predicted V	Correlation
0.0000	-3.5386	-18.7901	$V=6.911E-09R^{3.5386}Q^{-18.7901}$	0.17	0.00	-0.34
				0.48	0.00	
				0.70	0.00	
				2.14	0.00	
				3.70	0.00	
				3.78	0.00	
				3.06	0.00	
				0.43	0.00	
				3.51	0.00	
				3.13	0.00	
				3.06	0.00	
				4.30	0.00	
				3.19	0.00	
				0.64	0.01	
				1.54	0.00	
				0.54	0.00	
				0.59	0.00	
				0.62	0.00	
				3.19	0.00	
				1.54	0.00	
				2.62	0.00	
				1.30	0.00	
				3.18	0.00	
				2.32	0.00	
				0.73	0.03	
				2.11	0.00	
				2.65	0.00	
				3.41	0.00	
				1.44	0.00	

APPENDIX 18
SITE CONSTANTS AND PRODUCTION DATA USED TO DETERMINE COEFFICIENT OF
CORRELATION AT GOVERNMENT HILL USING USBM EQUATION

USBM -GH
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.95
R Square	0.90
Adjusted R	0.86
Standard Error	0.44
Observations	4.00

ANOVA					
	df	SS	MS	F	Significance F
Regression	1.0000	3.6967	3.6967	18.8059	0.0493
Residual	2.0000	0.3931	0.1966		
Total	3.0000	4.0899			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	5.6866	1.0944	5.1963	0.0351	0.9779	10.3952	0.9779	10.3952
(1/2lnQ-lnR	1.3152	0.3033	4.3366	0.0493	0.0103	2.6202	0.0103	2.6202

From the summary output above the constants can be tabulated and the equation written as follows:

K	B	Equation	Observed V	Predicted V	Correlation
294.8789	1.3152	$V=294.9R^{-1.31}Q^{0.66}$	0.17	0.13	0.73
			0.22	0.23	
			0.17	0.28	
			0.32	0.28	
			0.43	2.17	
			0.32	1.77	
			0.40	0.70	
			0.38	2.37	

APPENDIX 19

SITE CONSTANTS AND PRODUCTION DATA USED TO DETERMINE COEFFICIENT OF CORRELATION AT GOVERNMENT HILL USING AMHEN EQUATION

AMHEN -GH
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.943466112
R Square	0.890128305
Adjusted R Square	0.835192458
Standard Error	0.474004144
Observations	4

ANOVA

	df	SS	MS	F	gnificance F
Regression	1	3.640500198	3.6405	16.2030504	0.056534
Residual	2	0.449359856	0.22468		
Total	3	4.089860055			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	7.355546266	1.586964212		0.04353143	0.527386	14.1837	0.52738561	14.1837069
(1/3lnQ-lnR)	1.355015649	0.336624654	4.025301	0.056533888	-0.09336	2.8034	-0.0933643	2.80339564

From the summary output above the constants can be tabulated and the equation written as follows:

K	B	Equation
1564.8516	1.3550	$V=1564.8516R^{1.3550}Q^{0.6775}$

Observed	Predicted V	Correlation
0.17	0.54	0.73
0.22	0.99	
0.17	1.21	
0.32	1.21	
0.43	9.90	
0.32	8.06	
0.40	3.08	
0.38	10.88	

APPENDIX 20
 SITE CONSTANTS AND PRODUCTION DATA USED TO DETERMINE COEFFICIENT OF
 CORRELATION AT GOVERNMENT HILL USING LANKH EQUATION

LANKH -GH
 SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.957021
R Square	0.915888
Adjusted R Square	0.873833
Standard Error	0.414731
Observations	4

ANOVA					
	df	SS	MS	F	gnificance F
Regression	1	3.7458556	3.745856	21.77795	0.042979
Residual	2	0.3440044	0.172002		
Total	3	4.0898601			

	Coefficients	standard Errc	t Stat	P-value	Lower 95%	Jpper 95%	Lower 95.0%	Upper 95.0%
Intercept	4.109599	0.6898497	5.957239	0.02704	1.141414	7.07779	1.141413798	7.077785042
(1/2lnQ-3/4lnR)	1.701885	0.3646882	4.666685	0.042979	0.132757	3.27101	0.132757239	3.271012797

K	B	Equation
60.9223	1.7019	V=60.9223R ^{1.2764} Q ^{0.85095}

Observed	Predicted V	Correlation
0.17	0.00	0.71
0.22	0.01	
0.17	0.01	
0.32	0.01	
0.43	0.11	
0.32	0.08	
0.40	0.02	
0.38	0.12	

APPENDIX 21 SITE CONSTANTS AND PRODUCTION DATA USED TO DETERMINE COEFFICIENT OF CORRELATION AT GOVERNMENT HILL USING IS EQUATION

IS -GH
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.97823
R Square	0.95693
Adjusted R Square	0.9354
Standard Error	0.29677
Observations	4

ANOVA

	df	SS	MS	F	Significance F
Regression	1	3.9137127	3.913713	44.4368	0.0217716
Residual	2	0.1761474	0.088074		
Total	3	4.0898601			

	Coefficient	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-2.52196	0.5544411	-4.54865	0.045088	-4.907526	-0.13638727	-4.907525595	-0.13638727
(lnQ-2/3lnR)	1.65152	0.2477498	6.666093	0.021772	0.5855411	2.717505159	0.585541145	2.71750516

K	B	Equation
0.0803	1.6515	$V = 0.0803R^{1.1010}Q^{1.6515}$

Observed V	Predicted V	Correlation
0.17	0.02	0.70
0.22	0.08	
0.17	0.17	
0.32	0.17	
0.43	2.12	
0.32	1.66	
0.40	0.44	
0.38	2.42	

APPENDIX 22
SITE CONSTANTS AND PRODUCTION DATA USED TO DETERMINE COEFFICIENT OF
CORRELATION AT GOVERNMENT HILL USING GHND1 EQUATION

GHND1 -GH
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9974417
R Square	0.99489
Adjusted R Square	0.9846699
Standard Error	82.284848
Observations	4

ANOVA

	df	SS	MS	F	Significance F
Regression	2	1318229.2	659114.6	97.34669	0.071484508
Residual	1	6770.79622	6770.796		
Total	3	1325000			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-425.872	773.411993	-0.55064	0.679567	-10252.9611	9401.2	-10252.96106	9401.21698
(1/2lnQ-lnR)	-518.7207	181.549696	-2.85718	0.214331	-2825.51843	1788.1	-2825.518428	1788.07702
lnV	-199.2184	131.233401	-1.51805	0.370828	-1866.6897	1468.3	-1866.6897	1468.25293

K	B	α	Equation	Observed V	Predicted V	Correlation
4.3999E-01	-0.8210	0.001928	$V=4.3999E-01R^{0.8210}Q^{-0.4105}e^{-0.001928R}$	0.17	54.95	-0.84
				0.22	38.28	
				0.17	33.74	
				0.32	33.74	
				0.43	9.45	
				0.32	10.71	
				0.40	19.19	
				0.38	8.93	

APPENDIX 23
SITE CONSTANTS AND PRODUCTION DATA USED TO DETERMINE COEFFICIENT OF
CORRELATION AT GOVERNMENT HILL USING GHND2 EQUATION

GHDN2 -GH
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.997327792
R Square	0.994662724
Adjusted R Square	0.983988173
Standard Error	84.09453297
Observations	4

ANOVA

	df	SS	MS	F	Significance F
Regression	2	1317928.11	658964	93.1807495	0.073056662
Residual	1	7071.89048	7071.89		
Total	3	1325000			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-907.066027	964.75015	-0.94021	0.51961263	-13165.32644	11351.19	-13165.326	11351.19439
(1/3lnQ-lnR)	-502.334127	180.172553	-2.78807	0.21923805	-2791.633665	1786.965	-2791.6337	1786.96541
lnV	-225.709157	125.449989	-1.7992	0.32294965	-1819.69557	1368.277	-1819.6956	1368.277257

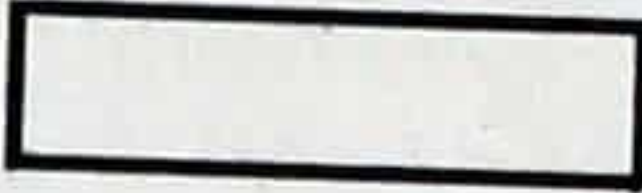
K	B	α	Equation	Observed V	Predicted V	Correlation
1.7976E-02	-2.2256	0.004430	$V=1.7976E-02R^{2.2256}Q^{-0.741861}e^{-0.004430R}$	0.17	8667.99	-0.76
				0.22	3253.12	
				0.17	2309.82	
				0.32	2309.82	
				0.43	73.43	
				0.32	102.94	
				0.40	500.80	
				0.38	62.92	

WARRANTY
INFORMATION
FOR THE
EQUIPMENT

APPENDIX 24
SITE CONSTANTS AND PRODUCTION DATA USED TO DETERMINE COEFFICIENT OF CORRELATION AT
GOVERNMENT HILL USING GEN EQUATION

GEN -GH
SUMMARY OUTPUT

Regression Statistics	
Multiple R	1.00
R Square	1.00
Adjusted R Square	1.00
Standard Error	0.07
Observations	4.00



ANOVA					
	df	SS	MS	F	Significance F
Regression	2.0000	4.0849	2.0425	412.1036	0.0348
Residual	1.0000	0.0050	0.0050		
Total	3.0000	4.0899			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-18.7901	2.7712	-6.7806	0.0932	-54.0008	16.4205	-54.0008	16.4205
lnQ (kg/delay)	3.5386	0.3264	10.8406	0.0586	-0.6089	7.6861	-0.6089	7.6861
lnR (m)	-0.5955	0.0945	-6.3012	0.1002	-1.7964	0.6053	-1.7964	0.6053

From the summary output above the constants can be tabulated and the equation written as follows:

K	B	A	Equation	Observed V	Predicted V	Correlation
0.0000	-3.5386	-18.7901	$V=6.911E-09R^{3.5386}Q^{-18.7901}$	0.17	0.00	-0.55
				0.22	0.00	
				0.17	0.00	
				0.32	0.00	
				0.43	0.00	
				0.32	0.00	
				0.40	0.00	
				0.38	0.00	