COMPARATIVE STUDY OF EMULSION AND WATER GEL EXPLOSIVES FOR ROCK QUARRYING

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Degree in Master of Science

Department of Earth Resources Engineering

University of Moratuwa

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Thesis submitted in partial fulfillment of the requirements for the degree

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DECLARATION

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Abstract

In the mining field, blasting is the predominant method for breaking of consolidated rocks and the main objectives are to extract the large quantity at both minimum cost and having minimum damage to the environment.

Rock breaking , over the years , which was limited to just breaking of boulders for the use of building and road construction has developed vastly to various aspects of mining namely ,open cast, underground and underwater blasting. Manually drilled single shot bore holes are disappearing and making way to multiple bore holes of immense depth with the introduction of the latest blasting technologies.

Result of the introduction of optimum blasting techniques and sustainable development criteria, mining industry has twisted in the path of eco-friendly mining. Explosives and blasting techniques that are used nowadays are based on the above concept.

Use of Dynamite changed to lesser powerful explosives such as Water Gel and then to Emulsion explosives. Our country also discarded the use of Dynamite several years ago and Water Gel explosives was introduced. Water Gel explosives is eco friendlier than Dynamite but could not be substituted in areas underground and underwater blasting. Introduction of Emulsion explosives was mainly to overcome these disadvantages of Water Gel Explosives.

Aim of this study is to carry out a comparative study in all areas of open cast mining and to ascertain the most appropriate high explosive type for optimum output.

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I would like to extend my sincere gratitude to my supervisors Professor P.G.R .Dhramaratna ,Senior Lecture Engineer P.V.A. Hemalal and Senior Lecturer Dr L.P.S. Rohitha of the Department of Earth Resources Engineering, University of Moratuwa Sri Lanka for the moral support and immense guidance given to me from the moment of choosing the appropriate thesis topic up to the completion of this MSc study.

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Blasting tests were performed at the "Metal Mix" quarries in Hanwella, Meepe area, which is belonging to Mr T.Illeperume, Senior Mining Engineer Mr M.D Wimal and Mining Engineer, Mr.S.Abeysundara extended valuable support and wish to extend my gratitude to them.

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Finally, I wish to extend my loving gratitude to my wife and sons for their moral support and unblemished encouragement made in fulfilling this enormous task.

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COMPARATIVE STUDY ON EMULSION AND WATER GEL EXPLOSIVES FOR ROCK QUARRYING

CHAPTER 1- INTRODUCTION

This chapter focuses on the history on application of primitive methodology in rock breaking, justification of problem and objectives of this study.

1. INTRODUCTION

Rock bash is the rough technique of striking one rock into another with great force and seeing what kind of edges/blades might break off. This can be a good way to make your first break into a stone, so that finer work can then be done with other methods such as percussion flaking. Safety precautions must be administered, as this is the least controlled and therefore most hazardous technique. Bi-polar percussion consists of carefully striking a hammer stone directly on top of your subject material while it is placed on an anvil stone. This often has a tendency to split the subject material in half, producing two usable edges. This is a very efficient way to create a quick stone tool. "Skipping stones", rocks that are flat with rounded edges, are easiest to break apart using bipolar percussion. The other system which is percussion flaking consists of using a hammer stone (or heavy billet) to strike the edge of the subject material to break off flakes. This is a controlled method for shaping an edge on a stone. Many rocks are difficult to effectively percussion flake because they are either too brittle or dense. The best materials to percussion flake are flints, cherts, obsidians, and glass.

1.1. Problem Statement and Justification

Dynamite was the premier and only high explosives used in Sri Lanka for mining during the period of late nineteenth century. The mega national projects mostly involved in the massive Mahaweli Multi-Purpose Development Projects introduced the use of Ammonium Nitrate for their large scale mining. Use of Dynamite coupled with Ammonium Nitrate became very popular. The unique property of Dynamite which consisted of a shelf life of three years or more and the ability to store for a larger duration was considered a security threat and was restricted during the last stages of the Eelam war and as a substitution Water Gel explosives was introduced in year 2011. The other main factor for the restriction of Dynamite was its high detonating velocity which resulted in negative impact on the environment too.

As described earlier introduction of Water Gel explosives initially gathered lot of criticism and due its low detonating velocity which resulted in lower production, inability to perform in underwater wet conditions and tunnel blasting and the requirement of a detonator for initiation. The only positive factor of Water Gel explosives were its low cost and the decision by the government to restrict Dynamite for security reasons. Anyway later on with adequate workshop and blasting tests conducted island wide users gradually accepted that it can be used in open cast mining.

In the meantime, during the last decade, national mega hydropower projects which were handled by international companies opted to import Emulsion explosives, quoting the reason that Water Gel explosives were unsuitable for underground and tunnel blasting. However, the world trend was moving forward for Emulsion explosives due to its slight advantage of producing better detonating power and ability to use in wet conditions when compared with Water Gel explosives. Water Gel explosives were manufactured by a single manufacture and the mining industry was facing a disadvantage of a sudden breakdown of the industry. In keeping with the latest trend the sole Water Gel explosives manufacture opted for the conversion of Water Gel explosives plant to Emulsion explosives which was granted approval. The sample production of this product has commenced and samples are distributed island wide to be tested for its suitability in the mining industry in Sri Lanka. Breaking the monopoly of this industry another manufacturer was also granted approval by Ministry of Defence for the manufacture of Emulsion explosives which is a very good sign for the future of the mining industry.

The main objective of this thesis is to study in detail the application of Emulsion explosives and the comparative study of it with Water Gel explosives. The author believes that this study is a very appropriate study on the eve of the launch of Emulsion explosives in Sri Lanka.

1.2. Objectives

The objective of the research described in this thesis to;

- Detailed study on selected properties of Emulsion Explosives.
- Comparative study with Water Gel explosives for rock quarrying in Sri Lanka.

1.3. Structure of the Thesis

Chapter 1	Focus on the history on application of primitive methodology in rock breaking, Justification of problem and objectives of this study .
Chapter 2	Literature review;
Chapter 3	Explain methodology used for research.
Chapter 4	Results and discussion
Chapter 5	Conclusions
Chapter 6	Recommendations and future research.
Chapter 7	Annexes
	References

CHAPTER 2 - LITRETURE REVIEW

2. LITRETURE REVIEW:

This chapter mainly focuses on primitive methods of rock breaking, properties of explosives and discussion on selected explosives and accessories which are commonly used in the quarry industry in Sri Lanka and the mechanism of rock breaking.

2.1. Primitive Methods of Rock Breaking

Following images of the primitive methodology which was practiced during the ancient era is illustrated in Figure 2.1, Figure 2.2 and Figure 2.3

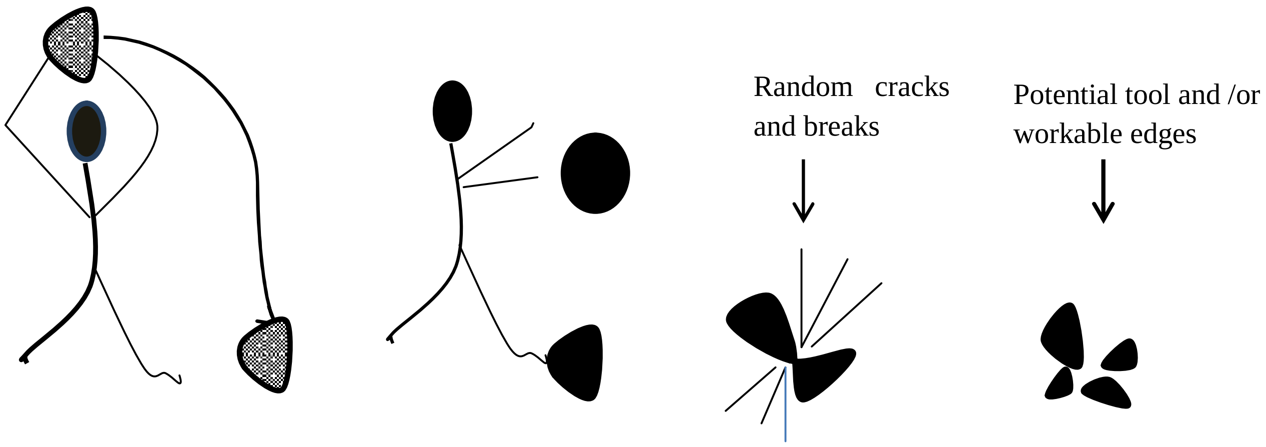

Figure 2.1: Image rock bash method

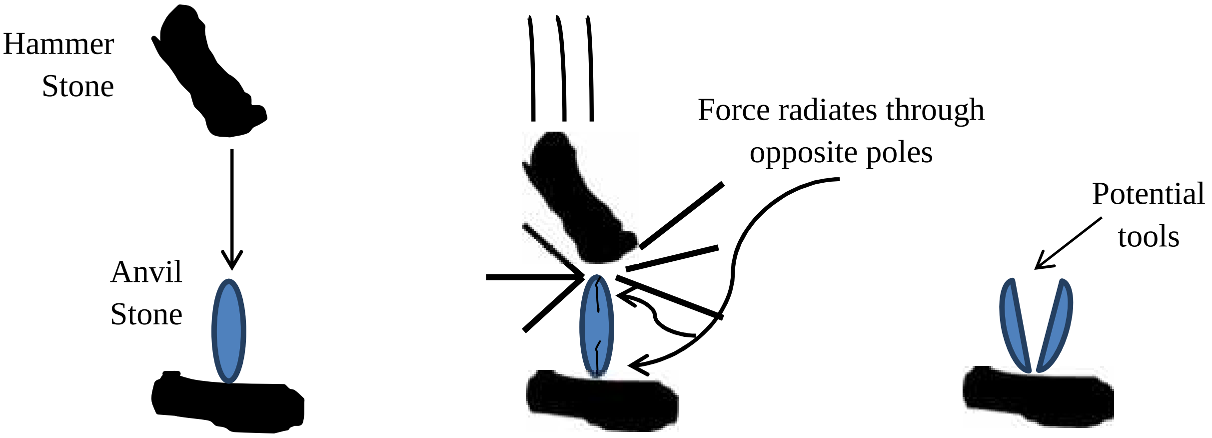

Figure 2.2: Image of bi polar percussion

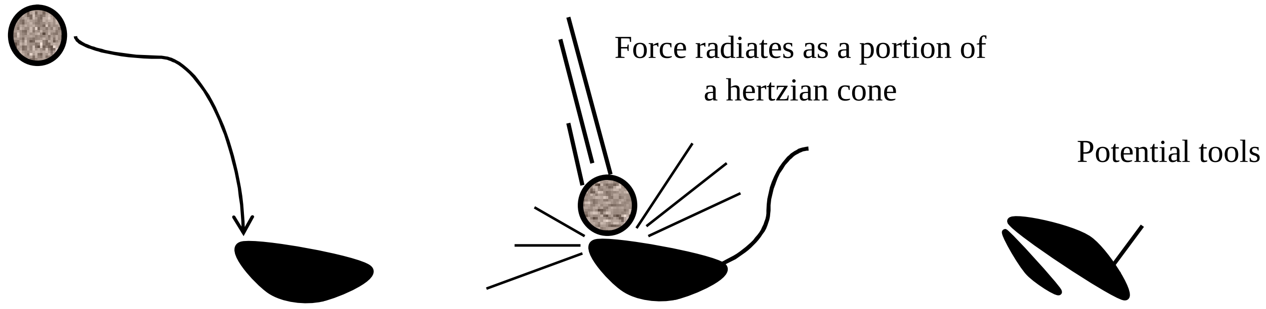

Figure 2.3: Image of percussion flaking

2.2. History of Blasting Accessories in Sri Lanka

The history of rock breaking technology in Sri Lanka (Ceylon) is centuries old and archeological facts explain that there existed a developed system of rock breaking.

The native population had used unique methods mostly invented by themselves. One **w**ay of separating boulders from the mother rock was by using firewood, heat the part of the area to be removed and allow to cool rapidly. This method is still being used in some remote areas in our country.

Another way of separating rock which was in practice during the ancient times was similar to extracting granite for flooring industry which is described below.

The Quarry Manager decides how to extract the blocks, the drilling can begin. The process starts by taking down a “bench wall,” a large dimensional chunk of rock that is then cut into smaller blocks which will eventually be sent to the factory for processing. The bench walls are cut using a combination of diamond wire cables, drills and even high temperature torches that would melt the stone. Dirt is pushed up against the base of the wall to cushion the fall, and small dynamite charges jar the wall loose to bring it down to a horizontal position. The blocks can then be drilled from the bench wall. Blocks of a given type of stone usually have a fairly uniform size, due to the size of the processing equipment used. Granite blocks of larger sizes usually weigh between 38-42,000 pounds, while lighter marble and travertine blocks weigh between 15-25,000 pounds.[1]

It is known that a similar methodology was adopted in ancient Sri Lanka with the only deviation was the use of fires and tools to separate blocks from the mother rock.

2.3. Properties of Explosives

In this chapter definition, classification, characteristic, properties of explosives and mechanism of rock breaking is discussed in detail.

2.3.1. Definition of Explosives

An explosive is a reactive substance that contains a great amount of potential energy that can produce an explosion if released suddenly, usually accompanied by the production of light, heat, sound, and pressure.

An explosive charge is a measured quantity of explosive material. This potential energy stored in an explosive material may be,

- Chemical energy, such as Nitroglycerin or grain dust
- Pressurized gas, such as a gas cylinder or Aerosol can.
- Nuclear energy, such as in the Fissile isotopes Uranium-235 and Plutonium-239

2.3.2. Classification of Explosives

Explosives are classified according to the following properties. They are,

- Sensitivity
- Velocity
- Priming composition
- Physical form

2.3.2.1. Classification According to the Sensitivity

There are three main classifications,

- Primary explosives
- Secondary explosives
- Tertiary explosives

2.3.2.1.1. Primary Explosives

A primary explosive is extremely sensitive to stimuli such as impact, friction, heat, static electricity, or electromagnetic radiation. A relatively small amount of energy is required for initiation. As a very general rule, they are considered to be those compounds that are more sensitive than Penta Ethritol Tetra Nitrate (PETN). As a practical measure, primary explosives are sufficiently sensitive that they can be reliably initiated with a blow from a hammer, however, PETN can also usually be initiated in this manner, so this is only a very broad guideline. Additionally, several compounds, such as Nitrogen Tri Iodide, are so sensitive that they cannot even be handled without detonating. Nitrogen Tri Iodide is so sensitive that it can be reliably detonated by exposure to Alpha radiation it is the only explosive for which this is true.

Primary explosives are often used in detonators or to trigger larger charges of less sensitive secondary explosives. Primary explosives are commonly used in blasting caps and percussion caps to translate a physical shock signal. In other situations, different signals, such as electrical/physical shock, or, in the case of laser detonation systems, light, are used to initiate an action, i.e., an explosion. A small quantity, usually milligrams, is sufficient to initiate a larger charge of explosive that is usually safer to handle.

2.3.2.1.2. Secondary Explosives

A secondary explosive is less sensitive than a primary explosive and requires substantially more energy to be initiated. Due to the less sensitive property, they are usable in a wider variety of applications and are safer to handle and store. Secondary explosives are used in larger quantities in an explosive train and are usually initiated by a smaller quantity of a primary explosive.

2.3.2.1.3. Tertiary Explosives

Tertiary explosives, also called blasting agents, are so insensitive to shock that they cannot be reliably detonated by practical quantities of primary explosive, and instead require an intermediate explosive booster of secondary explosive. These are often used for safety and the typically lower costs of material and handling. The largest consumers are large-scale mining and construction operations.

2.3.2.2. Classification According to the Velocity

There are Two main classifications,

- Low explosives
- High explosives

2.3.2.2.1. Low Explosives

Low explosives are compounds where the rate of decomposition proceeds through the material at less than the speed of sound. The decomposition is propagated by a flame front (deflagration) which travels much more slowly through the explosive material than a shock wave of a high explosive. Under normal conditions, low explosives undergo deflagration at rates that vary from a few centimeters per second to approximately 400 m/s. It is possible for them to deflagrate very quickly, producing an effect similar to a detonation. This can happen under higher pressure or temperature, which usually occurs when ignited in a confined space.

A low explosive is usually a mixture of a combustible substance and an Oxidant that decomposes rapidly (deflagration); however, they burn more slowly than a high explosive, which has an extremely fast burn rate .Low explosives are normally employed as propellants. Included in this group are petroleum products such as Propane and Gasoline, Gunpowder (both black and smokeless), and light Pyrotechnics, such as flares and fireworks, but can replace high explosives in certain applications.

2.3.2.2.2. High Explosives

High explosives (HE) are explosive materials that detonate, meaning that the explosive shock front passes through the material at a supersonic speed. High explosives detonate with explosive velocity ranging from 3 to 9 km/s. For instance, Trinitrotoluene (TNT) has a detonation (burn) rate of approximately 5.8 km/s (19,000 f/s), Detonating cord of 6.7 km/s (22,000 f/s), and C4 about 8.5 km/s (29,000 feet per second). They are normally employed in mining, demolition, and military applications. They can be divided into two explosives classes differentiated by sensitivity, primary explosive and secondary explosive. The term high explosive is in contrast with the term low explosive, which explodes (deflagrates) at a lower rate. It should be also noted that explosives are classified according to the priming composition and their physical form.[2]

2.3.2.3. Classification According to its Use

Explosives are used daily, world over for numerous functions and industries such as mining, military war heads, fireworks, paints, match, fertilizer, rubberized goods, soldering, food preservations, Ayurveda drug manufacture etc. Explosives can be mainly categorized into three major categories according to the mode of its usage, they are as follows,

- Military explosives
- Commercial explosives
- Improvised explosives

2.3.2.3.1. Military Explosives

Properties of selected commonly used military explosives are listed out in Table2.1,

Table2.1: List of military explosives

Name	Appearance	Uses	Sensitivity
C4 [Fourth Generation]/ [1,3,5-TriNitroPerhydro-1,3,5-Triazine] / [(RDX) 90%]	Smells like motor oil, light brown putty-like substance	Typical for demolition/ metal cutting/used to create targeted explosion/underwater operations	Non-toxic, insensitive to shock, will ignite and burn
HMX [Octahydro-1,3,5,7-Tetranitro-1,3,5,7-Tetrazocine] / [High melting Explosives] /[Octagon]	Odorless white or colorless crystals	Component of plastic explosives /Component of rocket propellant /Detonation of nuclear devices/ Booster charge for ammunition	Insensitive to heat, shock, and friction
PETN [Penta ErythritolTetra Nitrate] / [2,2-Bis{(Nitroxy) Methyl}Propane-1,3-DiyldiNitrate]	White crystalline solid or crystals, odorless	Booster and bursting charges of small caliber ammunition/ Base charges of detonators in some land mines and shells/ Explosive core of detonation cords/Ingredient of Semtex	Sensitive to heat, shock, and friction

2.3.2.3.2. Commercial Explosives:

Properties of selected commonly used commercial explosives are listed in Table 2.2 ,

Table 2.2 : List of commercial explosives

Name	Appearance	Uses	Sensitivity
Black Powder [Gunpowder or grain powder]	Coal black to cocoa brown	Primarily used in the core of military and commercial safety fuses Also used for fireworks, model rocket engines, and ammunition propellant for muzzle-loading guns	Extremely sensitive to heat, shock, and friction

Smokeless Powder	Small grains or pellets/usually black but can appear as shades of grey	Primarily used as standard propelling powder for ammunition in small arms Also used in mortar shells, artillery shells up to 280 mm, and as the propellant charge in naval artillery	Sensitive to heat, insensitive to shock and friction
ANAL [Ammonium Nitrate and Aluminum powder]		Certain commercial blasting water-based slurry explosives ammonium nitrate prills	Sensitive to heat but not shock and friction
Dynamite	Light brown to reddish tan/Gelatin dynamite thick to tough rubbery type	Commercial dynamite is used for construction, demolition, road building, and mining	All dynamite are insensitive to heat, shock, and friction
TNT / [Trinitrotoluene]	Pale yellow solid odorless	Primarily mines and demolition explosives/ used in booster explosives and missile and rocket propellants	Sensitive to heat/relatively insensitive to shock and friction

2.3.2.3.3. Improvised Explosives

Properties of selected commonly used commercial explosives are listed in Table 2.3,

Table 2.3: List of improvised explosives

Name	Appearance	Uses	Sensitivity
HMTD / [Hexamethylene triperoxidediamine] / [Hexamine peroxide]	Colorless white crystals or powder /stable below 70F	Extremely sensitive explosive with no commercial or industrial applications	Extremely sensitive to heat , shock and friction.
TATP/ [Triacetonetriperoxide] / [Acetone peroxide] / [Peroxyacetone]	White granular powder (similar to sugar) with an acrid smell	Common homemade explosive used in IED’s can be used as both as a booster/ short life of ten days only	Sensitivity to heat , shock and friction.

2.3.3. Properties of Explosive Materials

A detail study on the properties of explosives is of great importance and thereby can obtain a proper guideline for the user to determine the suitability of an explosive substance for a particular use, its physical properties must first be known. The usefulness of an explosive can only be appreciated when the properties and the factors affecting them are fully understood. Some of the more important characteristics are listed below and are discussed in detail in this chapter.

- Velocity of detonation
- Sensitivity
- Sensitivity to initiation
- Stability
- Power, performance, and strength
- Detonation pressure
- Brisance
- Density
- Volatility
- Hygroscopicity and water resistance
- Toxicity
- Explosive train
- Volume of products of explosion
- Oxygen balance
- Chemical composition
- Availability and cost

2.3.3.1. Velocity of Detonation

The velocity with which the reaction process propagates in the mass of the explosive. Most commercial mining explosives have detonation velocities ranging from 1800 m/s to 8000 m/s. Today, velocity of detonation can be measured with accuracy. This factor and density are important element influencing the yield of the energy transmitted for both atmospheric over-pressure and ground acceleration. By definition, a "low explosive," such as Gasoline, Black powder, or Smokeless Gunpowder has a burn (detonation) rate of less than 3,300 feet per second (1,006 m/s). In contrast, a "high explosive," whether a primary, such as detonating cord, or a secondary, such as Trinitrotoluene(TNT) or C4 explosives has a burn rate above that point.

Velocity of detonation can be measured by using the D’Autriche method. Figure 2.4 illustrates the apparatus used for calculating the Velocity of Detonation(VOD). General - the time lag between the initiation of two ends of, a length of detonating fuse of known velocity of detonation, inserted radially into an explosive charge at a known distance (m) apart, causes the two detonation fronts travelling in opposite direction along the length of the detonating fuse to meet at a point away from the center of the fuse where the distance is measured as (a), the velocity of the detonation of the detonating fuse is V_f, then the velocity of detonation of the unknown Explosive(V_u) is calculated and is expressed in meters per second (m/s) as follows[2],

$$\mathbf{V_u = V_f\ (m/2a)}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(01)$$

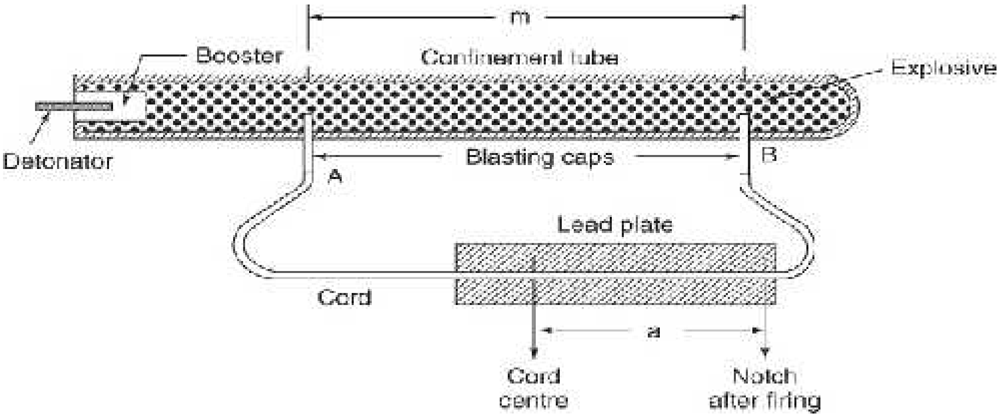

Figure 2.4:D’Autriche method

Table2.4 :Velocity of detonation on common Explosives:

Explosive class	Explosive name	Abbreviation	Detonation velocity (m/s)	Density (g/cm^3)
Aromatic	1,3,5-Tri Nitro Benzene	TNB	7,450	1.60
Aromatic	1,3,5-Triazido-2,4,6-Tri Nitro Benzene	TATNB	7,300	1.71
Aromatic	4,4’-Dinitro-3,3’-Diazenofuroxan	DDF	10,000	2.02
Aromatic	Tri Nitro Toluene/[2-Methyl -1,3,5-Tri Nitro Benzene]	TNT	6,900	1.60
Aromatic	Tri Nitro Aniline/[2,4,6,Tri Nitro Anline]	TNA	7,300	1.72
Aromatic	Tetryl/[N-Methyl-N-(2,4,6-Tri Nitro Phenyl)Nitramide		7,570	1.71

Aromatic	Picric Acid/[2,4,6-Tri Nitro Phenol]	TNP	7,350	1.70
Aromatic	Dunnite/[Ammonium2,4,6-Tri Nitro Phenolate		7,150	1.60
Aromatic	Methyl Picrate/[$O_2N)_3C_6H_2OCH_3$]		6,800	1.57
Aromatic	Ethyl Picrate/[(2E)-N-Hydroxy-2-Butanimine		6,500	1.55
Aromatic	Picryl Chloride/[2-Chloro-1,3,5-tri Nitro Benzene]		7,200	1.74
Aromatic	Tri Nitro Cresol/[2,4,6-tri Nitro-m-Kresol]		6,850	1.62
Aromatic	Lead Styphnate/[Lead(11)2,4,6-tri Nitro Benzene-1,3-Bis(Olate)]		5,200	2.90
Aromatic	Tri Amino Tri Nitro Benzene/[1,3,5-Triamino-2,4,6-Tri Nitro Benzene]	TATB	7,350	1.80
Aliphatic	1,1-Diamino-2,2-Dinitroethene	FOX-7	8,335	1.76
Aliphatic	Methyl Nitrate[Nitric Acid]/[Metyl Ester]		6,300	1.21
Aliphatic	Nitro Glycol/[1,2-Dinitroxy Ethane]	EGDN	7,300	1.48
Aliphatic	Nitroglycerine/[Propane-1,2,3-Triyl Tri Nitrate]/[1,2,3-Tris(Nitrooxy)Propane]	NG	7,700	1.59
Aliphatic	MannitolHexanitrate/[2R,3R,4R,5R)-Hexane-1,2,3,4,5,6-Hexol-1,2,3]	MHN	8,260	1.73
Aliphatic	Penta Erythritol Tetra Nitrate/{[(2R,3R)-1,3,4-Tri Nitroooxy Butan-2-y]Nitrite}	PETN	8,400	1.70
Aliphatic	Erythritol Tetra Nitrate/[{(2R,3R)-1,3,4-Tri Nitrooxy butan-2-yl}Nitrate]	ETN	8,100	1.60
Aliphatic	Ethylene Di Nitramine/[1,2-Di Chloro Ethane]	EDNA	7,570	1.65
Aliphatic	Cyclo Tri Methylene Tri Nitramine/ [2,2,6,6-Tetra Methyl Piperidinone]	RDX	8,750	1.76
Aliphatic	Cyclo Tetra Methylene Tetra Nitramine/ [Octahydro-1,3,5,7-Tetranitro-1,3,5,7-Tetrazocine]	HMX	9,400	1.91
Aliphatic	Nitro Guanidine/[1-Nitro Guanihdine]	NQ	8,200	1.70

Aliphatic	Hexa Nitro Hexa Azaisowurtzitane[2,4,6,8,10,12-Hexaazatetracyclo(5.5.$0^{3,11}$.$0^{5,9}$)dodocane	HNIW or CL-	9,500	2.04
Aliphatic	Tetra Nitro Glycoluril/ [Tetrahydroimidazo(4,5-d)imidazole-2,5(1H,3H)-Dione]	Sorguyl	9,150	1.95
Aliphatic	OctaNitrocubane	ONC	10,100	2.00
Aliphatic	Nitrocellulose/[Cellulose Nitrate]/[flash Paper]/[Flash Cotton]/[Gun Cotton]	NC	7,300	1.20
Aliphatic	Urea Nitrate	UN	4,700	1.59
Aliphatic	Acetone Peroxide/[3,3-Dimethyl-1,2-Dioxayclopropane]	AP or TATP	5,300	1.18
Inorganic	Lead Azide/[$Pb(N_3)_2$]		4,630	3.00
Inorganic	Silver Azide/[AgN_3]		4,000	4.00
Inorganic	Ammonium Nitrate/[NH_4NO_3]	AN	5,270	1.30
Aliphatic	Methyl Ethyl Ketone Peroxide/ [2,2-Peroxydi(butane-2-peroxol)]	MEKP	5,200	1.17
Aliphatic	Hexa Methylene Triperoxide Diamine/[3,4,8,9,12,13Hexaoxa-1,6-Diazabicyclo(4,4,4)Tetradecane]	HMTD	4,500	0.88
Inorganic	Mercury Fulminate/[Fulminated mercury]		4,250	3.00

2.3.3.2. Sensitivity

Sensitivity refers to the ease with which an explosive can be ignited or detonated, i.e., the amount and intensity of shock, friction, or heat that is required. Whenever term sensitivity is used, care must be taken to clarify what kind of sensitivity is under discussion. The relative sensitivity of a given explosive to impact may vary greatly from its sensitivity to friction or heat. Some of the test methods used to determine sensitivity relate to,

Impact- Sensitivity is expressed in terms of the distance through which a standard weight must be dropped onto the material to cause it to explode.

Friction- Sensitivity is expressed in terms of what occurs when a weighted pendulum scrapes across the material (it may snap, crackle, ignite, and/or explode).

Heat- Sensitivity is expressed in terms of the temperature at which flashing or explosion of the material occurs.

Sensitivity is an important factor in selecting an explosive for a particular purpose. The explosive in an armor-piercing projectile must be relatively insensitive, or the shock of impact would cause it to detonate before it penetrated to the point desired. The explosive lenses around nuclear charges are also designed to be highly insensitive, to minimize the risk of accidental detonation.

2.3.3.3. Sensitivity to Initiation

The index of the capacity of an explosive to be initiated into detonation in a sustained manner. It is defined by the power of the detonator which is certain to prime the explosive to a sustained and continuous detonation. Reference is made to the Sellier-Bellot[4] scale that consists of a series of 10 detonators, from 1 to 10, each of which corresponds to an increasing charge weight. In practice, most of the explosives on the market today are sensitive to a number 8 detonator, where the charge corresponds to 2g of Mercury Fulminate.

2.3.3.4. Stability

Stability is the ability of an explosive to be stored without deterioration. The following factors affect the stability of an explosive. They are as follows,

Chemical constitution,
Temperature of storage
Exposure to sunlight
Electrical discharge

The above factors are discussed separately in the following chapters.

2.3.3.4.1. Chemical Constitution

In the strictest technical sense, the word "stability" is a thermodynamic term referring to the energy of a substance relative to a reference state or to some other substance. However, in the context of explosives, stability commonly refers to ease of detonation, which is concerned with kinetics (i.e., rate of decomposition). It is perhaps best, then, to differentiate between the terms thermodynamically stable and kinetically stable by referring to the former as "inert." Contrarily, a kinetically unstable substance is said to be "labile." It is generally recognized that certain groups like Nitro (–NO_2), Nitrate (–ONO_2), and Azide (–N_3), are intrinsically labile. Kinetically, there exists a low activation barrier to the decomposition reaction. Consequently, these compounds exhibit high sensitivity to flame or mechanical shock. The chemical bonding in these compounds is characterized as predominantly covalent and thus they are not thermodynamically stabilized by a high ionic-lattice energy. Furthermore, they generally have positive enthalpies of formation and there is little mechanistic hindrance to internal molecular rearrangement to yield the more thermodynamically stable (more strongly bonded) decomposition products. For example, in Lead Azide,$Pb(N_3)_2$, the Nitrogen atoms are already bonded to one another, so decomposition into lead and N_2[I] is relatively easy.

2.3.3.4.2. Storage Temperature

The rate of decomposition of explosives increases at higher temperatures. All standard military explosives may be considered to have a high degree of stability at temperatures from –10 to +35 °C, but each has a high temperature at which its rate of decomposition rapidly accelerates and stability is reduced. As a rule of thumb, most explosives become dangerously unstable at temperatures above 70°C.

2.3.3.4.3. Exposure to Sunlight

When exposed to the ultraviolet rays of sunlight, many explosive compounds containing Nitrogen groups rapidly decompose, affecting their stability.

2.3.3.4.4. Electrical Discharge

Electrostatic or spark sensitivity to initiation is common in a number of explosives. Static or other electrical discharge may be sufficient to cause a reaction, even detonation, under some circumstances. As a result, safe handling of explosives and Pyrotechnics usually requires proper electrical grounding of the operator.

2.3.3.5. Power, Performance and Strength

The term power or performance as applied to an explosive refers to its ability to do work. In practice it is defined as the explosive's ability to accomplish what is intended in the way of energy delivery (i.e., fragment projection, air blast, high-velocity jet, underwater shock and bubble energy, etc.). Explosive power or performance is evaluated by a tailored series of tests to assess the material for its intended use.

2.3.3.6. Detonation Pressure

Detonation pressure data derived from measurements of shock waves transmitted into water by the detonation of cylindrical explosive charges of a standard size.

Detonation pressure is the pressure of detonation wave propagating through the explosive column and is the pressure in the reaction zone behind the detonation front at the Chapman–Jouguet[5]plane. It is a significant indicator of the ability of an explosive to produce desired fragmentation in a well-established burden. Although, the relationship of detonation velocity and density to detonation pressure is somewhat complex, and depends on the ingredients of an explosive, the following approximation is made,

$$\mathbf{P = 4.18 \times 10^{-7}\, DC^{2}\,(1 + 0.8D)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(02)$$

Where P – Detonation pressure (Kbar), (1 Kbar = 14,504 psi)

D - Specific gravity,

C – Detonation velocity (fps)

It is generally agreed that a high detonation pressure resulting in a strong shock wave is of major importance in very dense rock. Detonation pressures for commercial products range from about 5 to 50 kbar.

Borehole pressure, also called explosion pressure, is the pressure exerted on the borehole walls by the expanding gases of detonation after the chemical reaction has been completed. It is a function of confinement and the quantity and temperatures of gases of detonation. Borehole pressures generally is considered dominant in breaking softer or weaker rocks and in displacing all types of rocks encountered in blasting.

2.3.3.7. Brisance

In addition to strength, explosives display a second characteristic, which is their shattering effect or brisance (from the French meaning to "break"), which is distinguished and separate from their total work capacity. This characteristic is of practical importance in determining the effectiveness of an explosion in fragmenting shells, bomb casings, grenades, and the like. The rapidity with which an explosive reaches its peak pressure (power) is a measure of its brisance. Brisance values are primarily employed in France and Russia.

The sand crush test is commonly employed to determine the relative brisance in comparison to Tri Nitro Toluene (TNT). No test is capable of directly comparing the explosive properties of two or more compounds, it is important to examine the data from several such tests (sand crush, trauzl, and so forth) in order to gauge relative brisance. True values for comparison require field experiments.

2.3.3.8. Density

Density of loading refers to the mass of an explosive per unit volume. Several methods of loading are available, including pellet loading, cast loading, and press loading, the choice being determined by the characteristics of the explosive. Dependent upon the method employed, an average density of the loaded charge can be obtained that is within 80–99% of the theoretical maximum density of the explosive. High load density can reduce sensitivity by making the mass more resistant to internal friction. However, if density is increased to the extent that individual crystals are crushed, the explosive may become more sensitive. Increased load density also permits the use of more explosive, thereby increasing the power of the warhead. It is possible to compress an explosive beyond a point of sensitivity, known also as dead-pressing, in which the material is no longer capable of being reliably initiated, if at all.

Effect on the density by the addition of micro balloons in emulsion explosive charge density reveals that the largest decrease in density can be observed between the content of 0.6% and 1.0% of added micro balloons, while after crossing the 3.0% of additive, density change is not so significant. In order to determine parameters of obtained low density emulsion explosives there were tests carried out in order to appoint:

Detonation velocity (m/s)

Intensity of the air blast wave (db)

Density of Emulsion explosives, if reduced by the addition of the micro balloons and achieved the reduction level of the parameter in 48.87% of the initial Emulsion explosive charge density. Further reduction of the density by using micro balloons might cause difficulties in aspect of uniformity of charge. Even the addition of 3.0% of micro balloons changed the texture of the material drastically. Originally the material was very sticky and ductile, with the structure of jelly, while with increasing additions of micro balloons it became dry and agglomerating.

2.3.3.9. Volatility

Volatility is the readiness with which a substance vaporizes. Excessive volatility often results in the development of pressure within rounds of ammunition and separation of mixtures into their constituents. Volatility affects the chemical composition of the explosive such that a marked reduction in stability may occur, which results in an increase in the danger of handling.

2.3.3.10. Hygroscopicity and Water Resistance:

The introduction of water into an explosive is highly undesirable since it reduces the sensitivity, strength, and velocity of detonation of the explosive. Hygroscopicity is used as a measure of a material's moisture-absorbing tendencies. Moisture affects explosives adversely by acting as an inert material that absorbs heat when vaporized, and by acting as a solvent medium that can cause undesired chemical reactions. Sensitivity, strength, and velocity of detonation are reduced by inert materials that reduce the continuity of the explosive mass. When the moisture content evaporates during detonation, cooling occurs, which reduces the temperature of reaction. Stability is also affected by the presence of moisture since moisture promotes decomposition of the explosive and in addition causes corrosion of the explosive's metal container.

Explosives considerably differ from one another as to their behavior in the presence of Water. Gelatin Dynamites containing Nitroglycerine have a degree of water resistance. Explosives based on Ammonium Nitrate have little or no water resistance due to the reaction between Ammonium Nitrate and Water, which liberates Ammonia, Nitrogen Dioxide and Hydrogen Peroxide. In addition, Ammonium Nitrate is hygroscopic, susceptible to damp, hence the above concerns.

The water resistance of an explosive refers to its ability to detonate after its exposure to water. Gelled products such as Gelatin Dynamites and Slurries have good water resistance. Dry blasting agents such as ANFO, have practically no water resistance.

The standard water resistance test is used primarily, for classification of Dynamite explosive. The test is performed pinching 16 nos. 1/4-in diameter holes in a 1 ¼ x 8 in. cartridges of product, immersing these samples in water for various amounts of time (as per Table 2.5), and then testing the detonating ability of a No.6 strength detonator.

The product is then classified with regard to its ability to withstand water degradation.

Table 2.5 :Water resistant testing schedule

Class	1	2	3	4	5	6	7
Hours	indefinitely	32-71	16-31	8-15	4-7	1-3	Less than 1

2.3.3.11. Toxicity

There are many types of explosives which are toxic to some extent. Manufacturing inputs can also be organic compounds or hazardous materials that require special handing due to risks (such as carcinogens). The decomposition products, residual solids or gases of some explosives can be toxic, whereas others are harmless, such as Carbon Dioxide and Water.

2.3.3.12. Explosive Train

Explosive material may be incorporated in the explosive train of a device or system. An example is a pyrotechnic lead igniting a booster, which causes the main charge to detonate.

2.3.3.13. Volume of Products of Explosion

The most widely used explosives are condensed liquids or solids converted to gaseous products by explosive chemical reactions and the energy released by those reactions. The gaseous products of complete reaction are typically Carbon Dioxide, Steam, and Nitrogen. Gaseous volumes computed by the ideal gas law tend to be too large at high pressures characteristic of explosions. Ultimate volume expansion may be estimated at three orders of magnitude, or 01 ltr/gm of explosive. Explosives with an Oxygen deficit will generate soot or gases like Carbon Monoxide and Hydrogen, which may react with surrounding materials such as atmospheric Oxygen. Attempts to obtain more precise volume estimates must consider the possibility of such side reactions, condensation of steam, and aqueous solubility of gases like Carbon Dioxide.

2.3.3.14. Oxygen Balance

Oxygen balance is an expression that is used to indicate the degree to which an explosive can be Oxidized. If an explosive molecule contains just enough Oxygen to convert all of its Carbon to Carbon Dioxide, all of its Hydrogen to Water, and all of its Metal to Metal Oxide with no excess, the molecule is said to have a Zero Oxygen balance. The molecule is said to have a positive Oxygen balance if it contains more Oxygen than is needed and a negative Oxygen balance if it contains less Oxygen than is needed. The sensitivity, strength, and brisance of an explosive are all somewhat dependent upon Oxygen balance and tend to approach their maxima as Oxygen balance approaches Zero.

2.3.3.15. Chemical Composition

A chemical explosive may consist of either a chemically pure compound, such as Nitroglycerin, or a mixture of a Fuel and an Oxidizer, such as Black Powder or grain dust and air.

2.3.3.16. Availability and Cost

The availability and cost of explosives are determined by the availability of the raw materials and the cost, complexity, and safety of the manufacturing operations.[2]

2.3.4. Chemically Pure Explosive Compounds and Mixture of Oxidizer and Fuel

Some chemical compounds are unstable in that, when shocked, they react, possibly to the point of detonation. Each molecule of the compound dissociates into two or more new molecules (generally gases) with the release of energy.

2.3.4.1. Examples of Chemically Pure Explosive Compounds

Some examples of chemically Pure Explosive Compounds are listed in table 2.6,

Table 2.6 : Chemically pure explosive compounds

Explosive Type	Properties
Nitroglycerine/[Propane-1,2,3-Triyl Tri Nitrate]/[1,2,3-Tris(Nitrooxy) Propane]	A highly unstable and sensitive liquid.
Acetone Peroxide/[3,3-Dimethyl-1,2-Dioxaycloprоpane]	Very unstable white organic peroxide.

Tri Nitro Toluene/[2-Methyl -1,3,5-Tri Nitro Benzene]	Yellow insensitive crystals that can be melted and cast without detonation.
Nitrocellulose/[Cellulose Nitrate]/[flash Paper]/[Flash Cotton]/[Gun Cotton]	A nitrated polymer which can be a high or low explosive depending on nitration level and conditions.
RDX/Cyclo Tri Methylene Tri Nitramine/ [2,2,6,6-Tetra Methyl Piperidinone]	Very powerful explosives which can be used pure or in plastic explosives
PETN/PentaErythritol Tetra Nitrate/{[(2R,3R)-1,3,4-Tri Nitroooxy Butan-2-y]Nitrite}	Very powerful explosives which can be used pure or in plastic explosives
HMX/Cyclo Tetra Methylene Tetra Nitramine/[Octahydro-1,3,5,7-Tetranitro-1,3,5,7-Tetrazocine]	Very powerful explosives which can be used pure or in plastic explosives
C4 (Composition 4)	RDX plastic explosive plasticized to be adhesive and malleable.
Dynamite	A mixture of highly sensitive Nitroglycerin with sawdust, powdered silica, or most commonly diatomaceous earth, which act as stabilizers. Plastics and polymers may be added to bind powders of explosive compounds; waxes may be incorporated to make them safer to handle

2.3.4.2. Examples of Explosives with Mixture of Oxidizer and Fuel

An Oxidizer is a pure substance (molecule) that in a chemical reaction can contribute some atoms of one or more Oxidizing elements, in which the fuel component of the explosive burns. On the simplest level, the Oxidizer may itself be an Oxidizing element, such as gaseous or liquid Oxygen.

Some examples of Explosives with mixture of Oxidizer and Fuel are listed in table 2.7,

Table 2.7: Explosives with mixture of Oxidizer and fuel

Explosive Type	Properties
Black powder	Potassium Nitrate, Charcoal and Sulfur
Ammonal	Ammonium Nitrate and Aluminum Powder.
Flash powder	Fine metal powder (usually Aluminum or Magnesium) and strong Oxidizer (e.g. Potassium Chlorate or Per Chlorate).
Armstrong's mixture	Potassium Chlorate and Red Phosphorus. This is a very sensitive mixture. It is a primary high explosive in which Sulfur is substituted for some or all of the Phosphorus to slightly decrease sensitivity.
Sprengel explosives	A very general class incorporating any strong Oxidizer and highly reactive fuel, although in practice the name was most commonly applied to mixtures of Chlorates and Nitro Aromatics
ANFO	Ammonium Nitrate and fuel oil.
Cheddites	Chlorates or Per Chlorates and oil.
Oxyliquits	Mixtures of organic materials and liquid Oxygen.
Panclastites	Mixtures of organic materials and Di Nitrogen Tetroxide.

[2]

2.4. Commercial Explosives Oriented Industries in Sri Lanka

Commercial explosives are widely used in Sri Lanka for the under mentioned industries, they are mainly as follows,

- Metal quarry / mining industry
- Fireworks industry
- Match manufacturing industry
- Paint industry
- Ayurveda drug industry

Part of the Explosives which are required for the consumption of this industry is imported and others are locally manufactured. Ministry of Defence, State Trading Corporation, Government Stores at Welisra, Ragama and State Ayurvedic Corporation are the main institutions that are involved in the importation, storage and supply process.

The district supply of explosives is monitored by the Assistant Controllers of Explosives and authorized explosives dealers who are appointed island wide. Storage magazines are erected as per the requirement of the district with Tri forces and Police providing the day night security.

2.5. Commonly used Explosives in Sri Lanka

This section describes explosives, that are commonly used in Srilanka for the mining industry.

2.5.1. Blasting Powder

Gunpowder, also known as Black Powder (Figure 2.5) is the earliest known chemical explosive. It is a mixture of Sulfur, Charcoal, and Potassium Nitrate (Saltpeter). The Sulfur and Charcoal act as fuels, and the Saltpeter is an Oxidizer.

Figure 2.5 : Image of Blasting Powder

Gunpowder was invented in the Ninth century in China and the earliest record of a written formula for gunpowder appears in the Eleventh century Song dynasty text, Wujing Zongyao.[6]This discovery led to the invention of fireworks and the earliest gunpowder weapons in China. In the centuries following the Chinese discovery, gunpowder weapons began appearing in the Muslim world, Europe, and India. The technology spread from China through the Middle East or Central Asia, and then into Europe. The earliest Western accounts of gunpowder appear in texts written by English philosopher Roger Bacon in the Thirteenth century.

Gunpowder is classified as a low explosive because of its relatively slow decomposition rate and consequently low brisance. Low explosives deflagrate (i.e., burn) at subsonic speeds, whereas high explosives detonate, producing a supersonic wave. Ignition of the powder packed behind a bullet must generate enough pressure to force it from the muzzle at high speed, but not enough to rupture the gun barrel. Gunpowder thus makes a good propellant, but is less suitable for shattering rock or fortifications. Gunpowder was widely used to fill artillery shells and in mining and civil engineering to blast rock until the second half of the Nineteenth century, when the first high explosives were put into use.

2.5.2. Dynamite

Figure 2.6: Image of Dynamite

Use of Dynamite (image illustrated in Figure 2.6) initiated by Blasting Powder and Safety Fuse was practiced for a very long time. Dynamite result in detonations having very high shattering effect uncontrollable fly rocks was a major environmental issue. Another major negative aspect is health hazards associated with Dynamite and storing for long periods will result in oozing of highly sensitive Nitro Glycerin.

The main disadvantages of Dynamite are,

1. Classified as military explosives and due to this import export procedure were restricted.
2. Regional Asian countries do not manufacture and should be procured from East Asian or Europe which involves higher navigation charges.
3. Due to this factor importation requires longer time frame.
4. Comparatively more expensive than modern high explosives.
5. Dynamite exhibits a very high detonating velocity which results in comparative higher ground vibration and air blast over pressure and thereby it has a negative impact on the environment.

6. Expiry period of Dynamite is in the range of three years and the ability to store for longer periods will create opportunity to be used in insurgent activities. It is due to this factor the GOSL has restricted the use of Dynamite by normal civilians.
7. The adverse odor of Dynamite will create health hazards to the users.
8. Storing for longer periods and in adverse conditions will create oozing and the possibilities of accidents are higher.

2.5.3. ANFO (Ammonium Nitrate Fuel Oil)

Figure 2.7:Image of Ammonium Nitrate

Ammonium Nitrate Fuel Oil (ANFO- image illustrated in Figure 2.7) is the mixture of Ammonium Nitrate : fuel (95% : 5%) and with a substitution of dynamite by ANFO helped cut down on costs on explosives. The use of ANFO was indeed a tremendous boost for construction and development. This facilitated the blasting in holes of much deeper orientation.

It should be noted that though ANFO is classified as a less powerful explosive mainly a blasting agent and several large scale accident have occurred and reported and the handling, storage and transportation should be under professional guidance. The above blasting agent is an explosive that comprises ingredients that by themselves are non-explosive and can only be detonated by a high explosive charge placed within it and not by a detonator. All blasting agents contain the following essential components. Detonation curve for ANFO is illustrated in Figure 2.8.

Oxidizer	A chemical that provides Oxygen for the reaction. Typical Oxidizers are Ammonium Nitrate and Calcium Nitrate.

Fuel	A chemical that reacts with Oxygen to produce heat. Common fuels include fuel oil and Aluminum.
Sensitizer	Provides the heat source (‘hot spot’) to drive the chemical reaction of Oxidizer and fuel. Sensitizers are generally small air bubbles or pockets within the explosive.

“Explosives can sometimes be very unpredictable. People make mistakes every day it seems to be a part of being human. If you make a mistake with explosives, it will probably be your last mistake. The intent of this section is to demonstrate how a large number of educated, intelligent people can be killed and injured by explosives in spite of safety precautions and years of experience in dealing with explosives. Someone who does not have the training or experience will fare much worse when dealing with explosives”

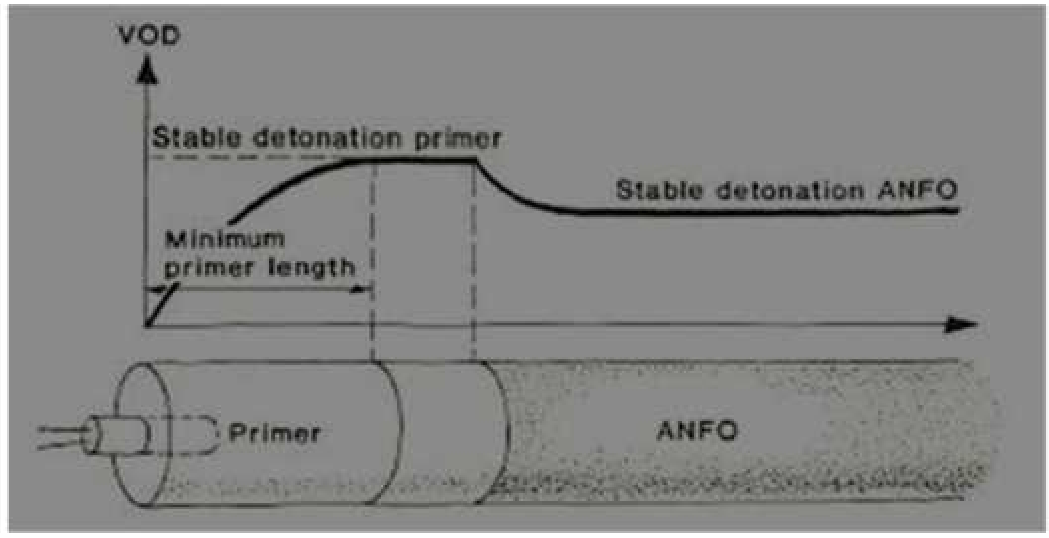

Figure 2.8: ANFO detonation curve

Worst disaster involving ANFO was in April 11, 1947in Texas City. The French cargo ship, S.S. Grandcamp, a 437-foot ship that arrived at Texas City Harbor on April 11, 1947 with 1420 tons of Ammonium Nitrate while No. 4 had 880 tons Ammonium Nitrate in hold No. 4 exploded which lifted the 7176-ton ship 20 feet into the air. Seconds later, the heat from this explosion detonated the fertilizer in hold No. 2. The two explosions were heard 150 miles away and killed all the firefighters on the scene and most of the spectators.

More damage was done when a 15-foot wave pushed out of the harbor dragged the Longhorn II, a 150-foot HCl barge, 200 feet inland onto some railroad tracks.[7]

2.5.4. Water Gel Explosives

During the latter part of Eelam war the GOSL was considering the restricting the use of Dynamite and finding alternative replacement for mining. The private sector was also involved in finding a remedy and Mr.K.P.R.Fernandoof Kelani Fireworks submitted a proposal in 2010 to manufacture Water Gel explosives (image of a cross section of a cartridge is illustrated in Figure 2.9) in Sri Lanka. This proposal was deeply studied by a committee appointed by Secretary of Defence and the approval was given to start a factory in Mirigama area in the Gampaha district. The manufacturing of Water Gel explosives was allowed after sample tests carried out island wide which was successful.

Figure 2.9: Image of Water Gel explosives

Water Gel explosives were marketed in 2011. The application of Water Gel, which is cap sensitive was different from Dynamite and initial stage there was a fairly big objection from the users. With the aim of safeguarding the industry initially both Dynamite and Water Gel explosives were issued according to an equal ratio and gradually reducing Dynamite .The transformation of changing from Dynamite to Water Gel took only Two years and by year 2013, the authorized explosive dealers made requests to the issuing authority at Ministry of Defence that they do not require Dynamite any more since permit holders were rejecting the use of Dynamite. The remaining stocks of Dynamite was reaching the expiry period and in order to minimize the loss to the government, steps were taken to reduce the selling price of Dynamite and dispatch major stocks to national mega projects but still later on a fair amount of stocks which reached expiry period had to be destroyed under the supervision of the Controllers of Explosives in the area.

Main advantages of Water Gel explosives are,

- User and eco friendly when compared to Dynamite
- Less ground vibration and air over pressure
- Price of this commodity lesser than Dynamite and does not affect much with international price variations.
- Locally manufactured and fairly new stocks available in the market
- Adequate stocks due to local manufacture
- No reported health hazards.

Main disadvantages of Water Gel explosives are,

- Less detonating velocity results in less output
- Ineffective in under water conditions and wet conditions.
- Dynamite is wrapped in wax paper but Water Gel consisted of a plastic tube which emits toxic fumes.

2.5.5. Emulsion Explosives

Dynamite was the first high explosive that was used in the mining industry for a very long time in our country and due to various reasons, which are already described in chapter 2.5.4, Water Gel explosives was introduced in 2011. Water Gel explosives were never a substitute for Dynamite which resulted in major international projects opting to import Emulsion explosives for National mega development projects. This attitude and the success of Emulsion over Water Gel explosives prompted the local Water Gel manufacture to convert his factory to produce Emulsion Explosives after making suitable adjustments in the factory. Another local manufacture also opted to manufacture Emulsion explosives and thereby ending the monopoly of Water Gel production.

This study is more appropriate since Emulsion explosives are now being manufactured and samples are distributed Island wide with the aim of testing its suitability. The image illustrated in Figure 2.10 exhibits both type of emulsion products which are sausage and cartridge types.

Figure 2.10: Image of Emulsion Explosives[8]

2.5.5.1. History of Emulsion Explosives

The history of emulsion explosives began in 1961 when Richard Egly and Albert Neckar of Commercial Solvents Corporation filed a patent application with the U.S. Patent Office for a blasting agent composed of a blend of a Water-in-Oil Emulsion and a solid oxidizing agent such as Ammonium Nitrate. This was granted in 1964 as U.S. Patent 3/161/551.[8]

2.5.5.2. What is an Emulsion Explosive

Emulsion explosive is a type of explosive in which very small particles of Oxidizers in aqueous phase are surrounded by a film of fuel in the Oil phase and vice-versa in such a manner that both the phases are in intimate contact with each other.

Upon touching, it gives the feel of industrial Grease. Emulsions share most of the same properties as slurries. The main difference is the mixture of the explosive components. Emulsions are prepared in the form of Water-in-Oil Emulsions. The internal phase is composed of a solution of Oxidizer salts suspended as microscopically fine droplets, which are surrounded by a continuous fuel phase. The emulsion thus formed is stabilized against liquid separation by an emulsifying agent.

As the components of an Emulsion explosive are microscopic in size and the Oxidizer and fuels are so intimately mixed, Emulsions have a very high Velocity of Detonation (VOD) and the resulting chemical reaction or detonation releases essentially all of the stored energy.

2.5.5.3. Characteristics of Emulsion Explosives

Emulsion explosive is composed of separate, very small drops of Ammonium Nitrate solution and other Oxidizers densely dispersed in a continuous phase, which is composed of a mixture of mineral Oil and Wax.

The Oil /Wax mixture, which is the fuel, is in this way given a very large contact surface to the Oxidizer, the Ammonium Nitrate solution. What distinguishes the Emulsion explosives from other liquid and plastic explosives is that they can be made to detonate without the addition of a sensitizer which in itself is an explosive. Small cavities are mixed in i.e. in form of micro balloons with a diameter of about one tenth of a millimeter in order to make the emulsion imitable. These collapse under the influence of the initiating shock wave from the blasting cap, creating multitude of local hot spots where the temperature is sufficiently high to start a fast explosive combustion of the explosives.

The density of the explosive and its capacity of initiation can be adjusted with the amount of micro balloons in the Emulsion explosive.

The strength is regulated by the amount of the additive fuel, Aluminum that is added. Furthermore there are considerable possibilities to vary the consistency to fit different purposes. This can be determined mainly by the proportion oil/wax. With the high percentage of wax, margarine like consistency is obtained. With more oil, grease like pumpable qualities can be obtained. The margarine type of Emulsion explosives is best suited for cartridge explosives. The tamping characteristic are excellent making it possible to utilize the blast hole volume to almost 100 %.

Because of the physical nature and properties of emulsion explosives , they retain their consistency over a wide temperature range , the tamping and pumping characteristic are virtually unchanged from $-20^{0}C$ to $+35^{0}C$.

The stability of Emulsion is outstanding, compared with other civil explosives. The detonator properties remain unchanged over long periods of time under normal storage conditions.

The velocity of detonation is high for Emulsion explosives but may decrease somewhat if the diameter is decreased or aluminum is added. Thanks to the fact that the water soluble drops of Ammonium Nitrate in the emulsion are completely surrounded by an oil/wax film, the explosives become water repellent, thus being highly water resistant.

The senility of emulsion explosives may vary from a high explosive which may be initiated by a #48 strength detonator to blasting agent products requiring a primer for initiation. From a handling point of view the emulsion explosives are very safe and a high degree of impact needed for accidental initiation.

Emulsion explosives were also invented during the same time period as Water Gel explosives. The main advantage of Emulsion explosives is was that it could be used very effectively in wet and underground conditions and it had a superior detonating velocity resulting in more production.

2.5.5.4. Properties of Emulsions Explosives

Following chapters describes the properties namely physical form, velocity of detonation, detonation pressure, sensitivity water resistance of Emulsion Explosives.

2.5.5.4.1. Physical Form

Emulsion explosive is an intimate mixture of two immiscible liquids with one liquid phase dispersed uniformly throughout the second phase. Emulsion explosives are dispersions of water solutions of Oxidizers in an oil medium or “Water-in-Oil” Emulsions (as illustrated in Figures 2.11 and 2.12). It is this unique structure and the high ratio of oxidizer to fuel that give Emulsion explosives their special characteristics. The viscosity of the Emulsion is controlled by the nature of the fuel phase and the droplet size. The composition (wax, oil, and emulsifier) of the full fuel phase has the greatest influence on the final viscosity of the product. Low viscosity oils, such as No. 2 diesel fuel, can be used to make pumpable Emulsions. Waxes and high viscosity oils are used to make thick, putty-like packaged products. The droplet size is controlled by the amount of work put into the Emulsion explosive. The faster and longer it is stirred, the greater the work input and the smaller the droplet size and size distribution.

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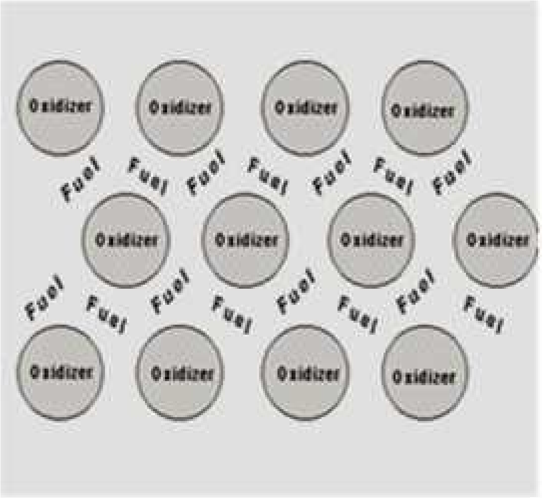

Figure 2. 11

Oxidizer surrounded by fuel

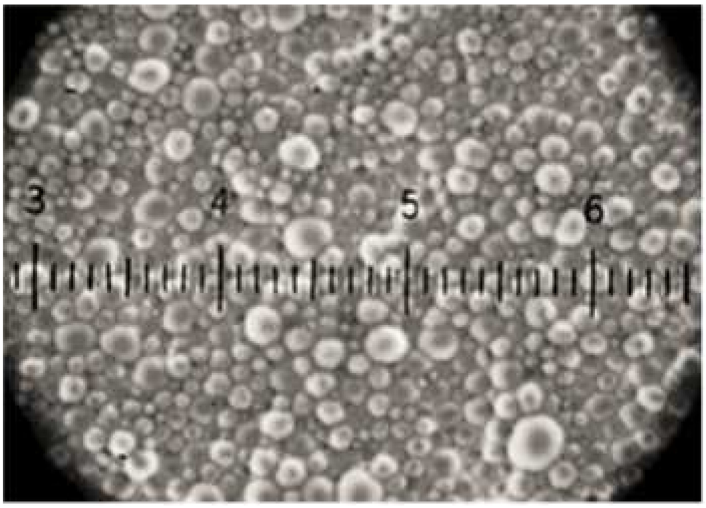

Figure 2. 12

Typical water-in oil seen under microscope

Observed through a microscope the structure of Emulsion explosive resembles that of a honey comb. The thickness of the Oil and the Wax membranes separating the droplets is less than one ten thousand of a millimeter. This involves an extremely large contact area between the fuel-oil and wax and the Oxidizer Ammonium Nitrate. As a result very rapid and complete explosives combustion is obtained. The oil and wax membrane also protects every droplet of Ammonium Nitrate and makes the explosive highly water resistance.

By adding “hot spots” in the form of hollow glass spheres (microspheres) or air bubbles the sensitivity of the Emulsion explosives can be varied. The hot spots, which are only one tenth of a millimeter in diameter act as density gradients in the explosives and effectively transfers shock wave energy to heat and enhance the rapid explosives combustion of the emulsion explosives,

2.5.5.4.2. Velocity of Detonation (VOD)

It is an established fact that the smaller the particle size of the ingredients of an explosive, the higher the velocity of detonation (VOD). Since the droplet size of Emulsions explosive is so fine, the VOD of Emulsion Explosive is very high, close to theoretical. The VOD does decrease somewhat as the charge diameter decreases or as solids such as Aluminum or Ammonium Nitrate(AN)prills are added, but the VOD generally remains relatively high when compared to most Water Gels.

2.5.5.4.3. Detonation Pressure

Since Emulsion explosive have a high velocity of detonation and a reasonable density, they also have a relatively high detonation pressure. Detonation pressures of Emulsion explosive is measured by the “aquarium” technique, and are found to be between 100 and 120 Kbar/ (1.45 - 1.74 x 106psi). As a result, Emulsion explosive are particularly well-suited for improving fragmentation in hard massive rock, for breaking hard bottom rock, and for use as a booster for ANFO mixtures and other blasting agents.

2.5.5.4.4. Sensitivity

Emulsion explosive have a very fine particle size and are extremely intimate mixture of Fuel and Oxidizer, only a density reducing agent needs to be added to make them detonable. It is not necessary to use high explosives or chemical sensitizers for sensitivity. The sensitivity of the Emulsion explosive can be made to vary from that of a No. 8 strength detonator (or less) for a high explosive classification at 68F (-20^{0}C) to booster sensitivity for blasting agents. The Emulsion explosive is sensitive over a wide temperature range, and they also maintain their sensitivity over a wide range of diameters generally, the lower the density of an Emulsion explosive, the more sensitive it becomes. Also, the lower the water content of the Emulsion explosive, the more sensitive it becomes. The water content of blasting agents is usually higher than that of Emulsion explosive, but so is the density. This keeps the overall bulk strength energy level of blasting agents close to that of the high explosive Emulsion.

2.5.5.4.5. Water Resistance

Water-in-oil emulsion has a continuous, water-immiscible oil phase and is extremely water resistant. They do not depend upon the integrity of the package for water resistance. Emulsion explosive is a good choice when wet holes are encountered, because they will perform successfully after sleeping underwater for weeks or even months.

2.5.5.5. Classification of Emulsion Explosive

Emulsion explosive is classified as Class-2 Nitrate Mixture class under regulations of the Explosives Act, Sri Lanka.

The classification is Class-1 (gun powder), Class-2 (Nitrate mixtures), Class-3 (Nitro-compound), Class-4 (Chlorate mixture) etc.

Water gel and Emulsion both comes under the Class-2 explosives.

2.5.5.6. Types of Emulsions

Emulsion explosive is mainly broadly divided into two types. They are,

Water-in-Oil Type (W/O)
Oil-in-Water Type (O/W)

2.5.5.6.1. Water-in-Oil Type (W/O)

In Water-in-Oil types, the aqueous phase is dispersed into an oil phase. Tiny particles of oxidizers (aqueous phase) are enveloped in a film of oil (fuel phase), thus the fuel phase is the outer, continuous phase and the Oxidizer blend (aqueous phase) remains in the inner phase.

2.5.5.6.2. Oil-in-Water Type (O/W)

In Oil-in-Water types, the outer (i.e. continuous phase) is aqueous phase (oxidizer blend) and the inner phase is oil (fuel blend) based. [8]

2.5.5.7. Bulk Emulsion Explosives

Most of the Swedish metal quarries work with drilling equipment for 64 up to 125 mm drill holes. Use of bulk Emulsion explosive systems, it had become possible to double the number of drill holes per round despite charging time has been reduced and better fragmentation has resulted in decreased costs for secondary blasting. The image 2.13 shows bore holes being charged by a bulk Emulsion explosives loaded truck.

Figure 2.13: Image of bulk Emulsion Explosives loaded in a truck[8]

2.5.6. Initiating Explosives

Properties and mechanism of initiating explosives such as Safety Fuse, Plain and Electric Detonators, Detonating Cord , Non Electric Detonators and Electronic Detonators are described in the following chapters.

2.5.6.1. Safety Fuse

This is the primary stage of explosives being used for rock breaking. The resultant blast will mainly produce boulders and thereafter secondary blasting was required to produce smaller sizes. Blasts could not be controlled and bore holes were limited to several feet.

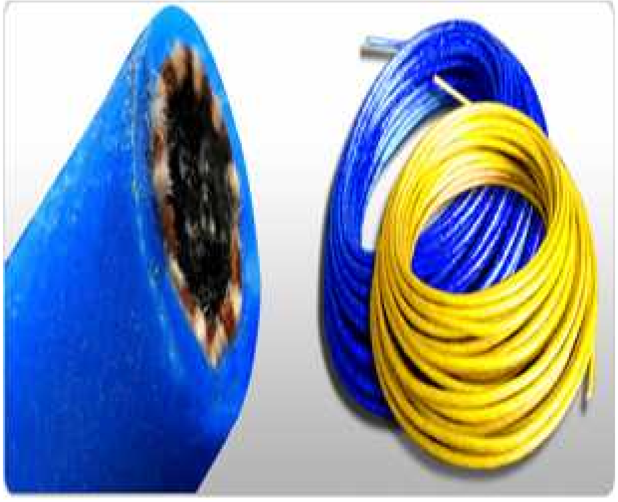

Figure2.14 :Image of Safety Fuse[2]

2.5.6.2 Detonators

Detonators are compact devices that are designed to safely initiate and control the performance of larger explosive charges. They contain relatively sensitive high explosives which can be initiated by electrical or shock energy from an external source. All detonators contain components that can be initiated by sufficient impact, heat, friction or electrical energy. These characteristics make them the most dangerous explosive products in industrial application and they must be stored, transported, handled and used according to set procedures, specified in codes and regulations.

Electric Detonators

Electric detonators are widely used to initiate blast sequences but are rarely now used inside the Blast holes themselves. Electrical energy is introduced into the detonator from the exploder (battery, hand-driven magneto or charged capacitor) via a primary circuit wire (shot firing cable) and detonator leads. In the detonator, the current heats up a high resistance wire which then ignites a fuse head (similar to a match). The resulting flash ignites a delay element which burns through to a primer charge that detonates the base charge. The timing of the Pyrotechnic delay element is accurate to within 8 milliseconds.

An image of an electric detonator is illustrated in Figure2.15 and a cross section of an electric detonator is illustrated in Figure 2.16.

Figure 2.15:Image of an electrical detonator

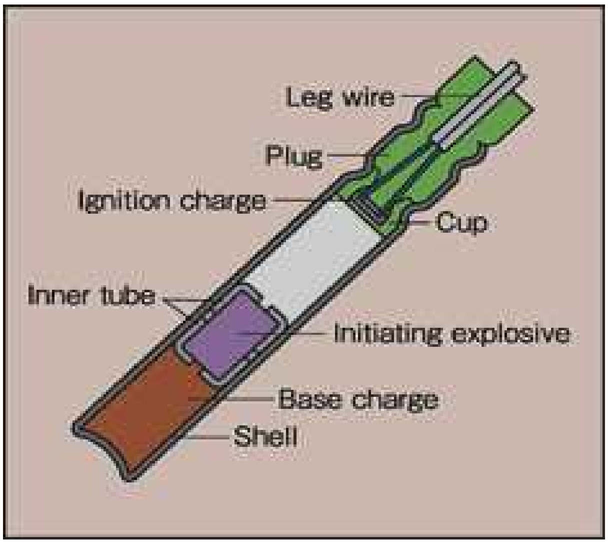

Figure 2.16: Cross section of an electrical detonator

2.5.6.3. Detonating Cord

Detonating cord is a strong, flexible linear explosive which consists of a continuous core of high explosive, covered by a plastic ‘jacket’ and is often overwrapped with textiles (image of detonating cord is illustrated in figure 2.14). The high explosive used is Penta Erythritol Tetra Nitrate (PETN), at a content of 3.6 to 70 g/m.

When initiated, detonating cord will detonate along its entire length at a VOD of between 6000 and 7500 m/s and with very high shock energy. This shock energy is sufficient to initiate a detonator-sensitive explosive or a signal tube. Detonating cord is usually initiated by means of an electric detonator.

Figure 2.17: Image of a detonating cord.

The great advantage of detonating cord is that it is an effective, but violent, means of transmitting energy for explosives initiation. Detonating cord trunk lines can be laid out between rows of holes with signal tube connection to individual blast holes or to a single row of blast holes. Delays can be introduced into detonating cord lines by means of millisecond connectors (MSCs). MSC's consist of two plastic blocks, each containing an identical delay detonator, linked by a short length of signal tube.

2.5.6.2.1 Signal (shock) tube

The signal tube system consists of narrow plastic tubes coated on the inside surface with a very thin layer of high explosive, typically Cyclo Tetra Methylene Tetra Nitramine(HMX) or Penta Erythritol Tetra Nitrate (PETN). One kilometer of tube will contain about 5 grams of HMX. Signal tube can be initiated by an Electric Detonator, Detonator Cord or mechanical shot shell starter device. The resulting shock wave travels at high speed of about 2000 m/s down the tube and sets off a Detonator at the other end. (Because of the way in whichthe tube works it is sometimes known as 'shock tube'.) The 'explosive shock wave' in the tube isnot sufficient to break the tube, indeed, a length of tube can safely be held in the hand when it is initiated.

The main advantages of this initiation system are

- It is not susceptible to stray electric currents,
- Separate lengths of signal tube cannot initiate each other through direct contact, knots or other simple connections,
- The tube is robust, having a high tensile strength and abrasion resistance,
- The initiation is virtually non-violent compared to detonating cord and is hence much safer to use.

2.5.6.2.2 Electronic Delay Detonators

The latest development in explosive technology is the Electronic Delay Detonator (EDD-cross section in Figure 2.18). Each Detonator incorporates a micro-processor chip, contained within a lengthened version of the PVC end plug, which controls the time at which the fuse head ignites and therefore the delay.

An electronic console is used to test and program the delay time for each Detonator. Delays can be set in increments from 1 to 6000 milliseconds. The circuit can be fired either manually or by computer. With the manual system, each Detonator is programmed individually using the console. In computerized firing, each Detonator is assigned an 'order number' from the console. A pre-determined firing pattern is then downloaded from a laptop. The main disadvantage is that the cost of one unit of a Detonators is up to four times per unit that ofother types.

Figure 2.18: Image of an Electronic Detonator

2.5.6.2.3 Non Electric Detonators

Non Electric Detonator is a shock tube Detonator designed to initiate explosions, generally for the purpose of demolition of buildings and for use in the blasting of rock in mines and quarries. Instead of electric wires, a hollow plastic tube delivers the firing impulse to the detonator, making it immune to most of the hazards associated with stray electric current. It consists of a small diameter, three-layer plastic tube coated on the innermost wall with a reactive explosive compound, which, when ignited, propagates a low energy signal, similar to a dust explosion. The reaction travels at approximately 6,500 ft/s (2,000 m/s) along the length of the tubing with minimal disturbance outside of the tube. The design of Non Electric Detonators incorporates patented technology,[9] including the Cushion Disk (CD) and Delay Ignition Buffer (DIB) to provide reliability and accuracy in all blasting applications.

Non electric detonators was invented by the Swedish company Nitro Nobel in the 1960s and 1970s, under the leadership of Per-Anders Person, and launched to the demolitions market in 1973.Nonel is a contraction of "Non electric detonators"

Figure 2.19 : Image of NONEL detonator

Figure 2.20: Image of NONEL detonators

2.6 Mechanism of Rock Breakage

This is a very important section of the study and this will create a very clear environment for the user of high explosives to get valuable information with regard to the whole blasting process inside a bore hole. This will undoubtedly encourage the user to optimize his blasting methodology to receive maximum output with less damage to the environment in future.

Two broad areas of breakage mechanisms include:

1. The role of stress waves generated from the explosive detonation (shock) force,
2. The role of borehole pressures by the detonation gas products.

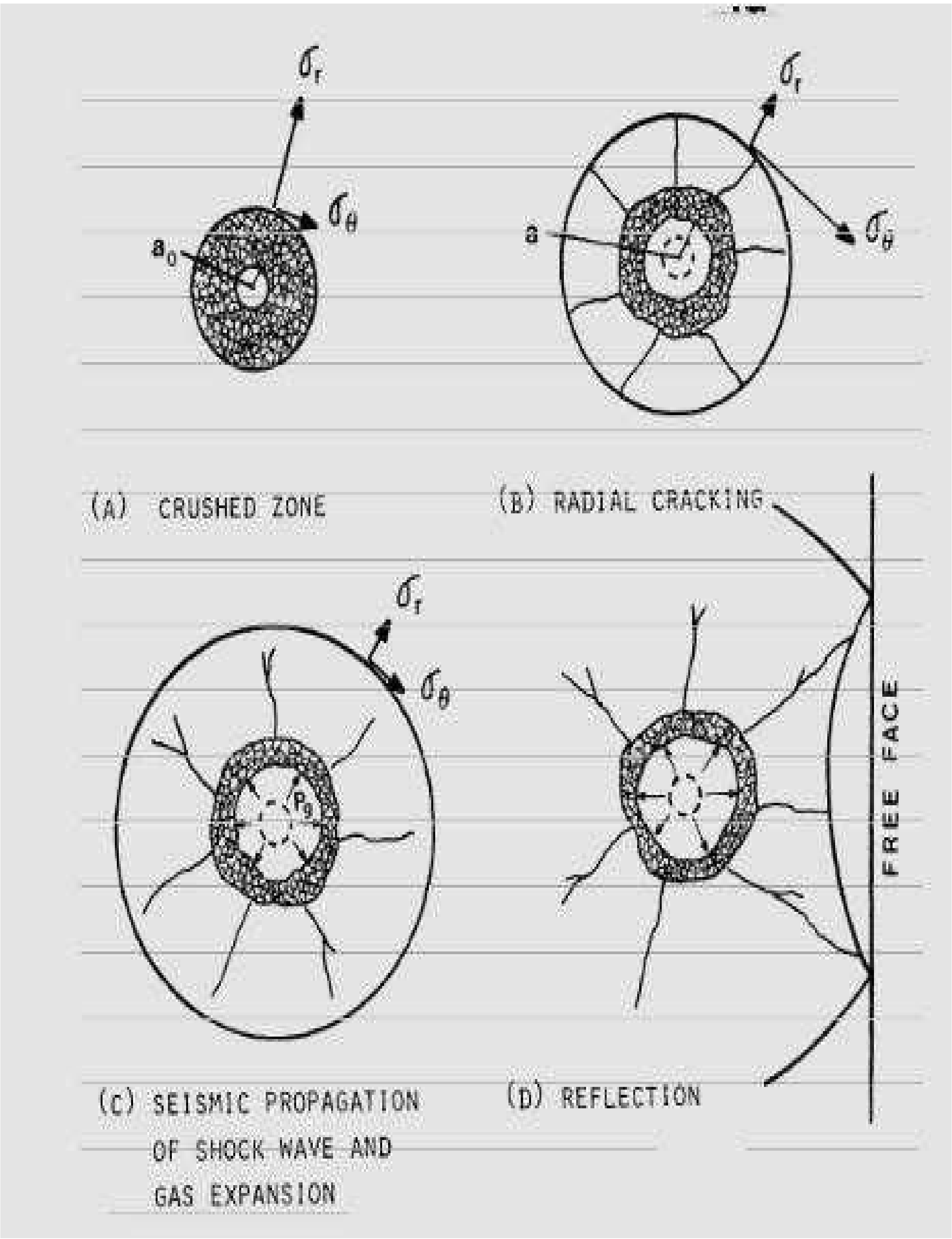

Figure 2.21: Image of mechanism of rock breaking

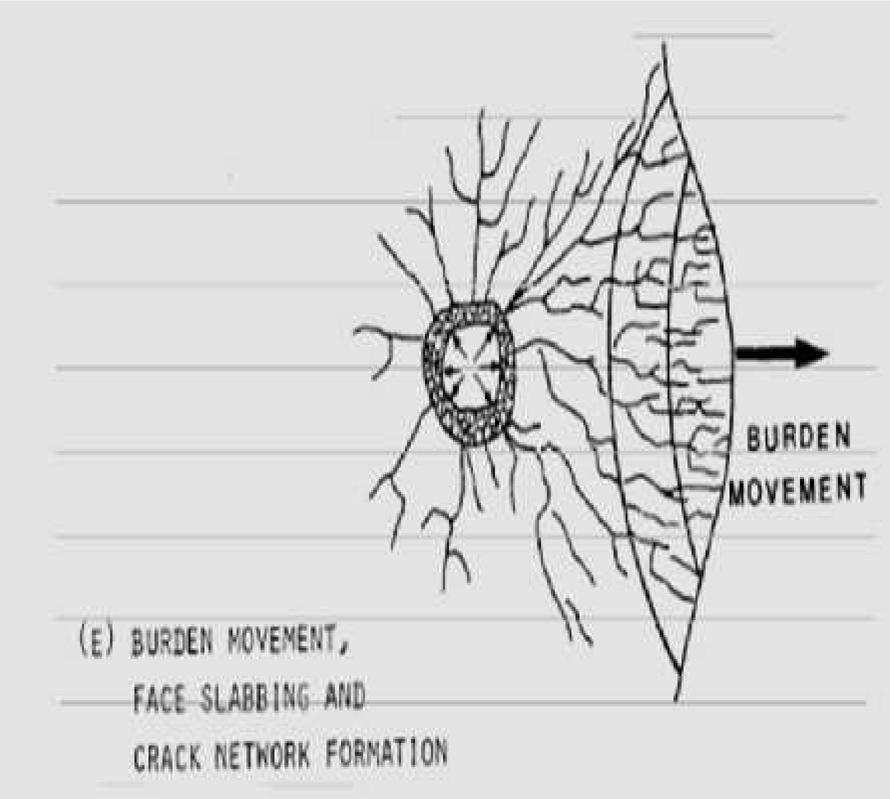

Figure 2.22: Image of mechanism of burden movement

Upon detonation within a borehole, a shock wave is generated and travels into the rock, quickly decaying in peak pressure amplitude and dispersing in shape as the wave travels away from the borehole. The cylindrically divergent wave carries both a radial and tangential stresses components. The response to the rock adjacent to the borehole is shown in Figure 2.21

Close to the borehole, the radial component carries a high compressive stress exceeding the dynamic compressive strength of the rock. The rock experiences intense shearing in this zone. At greater distance from the borehole, this component accentuates below the rock strength, defining the end to the crushing zone.

The tangential component carries a tensile phase that rapidly increases to a level greater than the dynamic tensile rock strength. The rock surrounding the borehole develops radial fractures as the rock fails in tension. Once the tensile tail of the component attenuates below the tensile strength, the fractures cease, and the wave travels radially away as an elastic sound wave.

Depending on the explosive and the rock strengths, characteristic degrees of rock damage occur at varying distances from the borehole. The crushed zone ranges from 2 to 4 borehole radii away from the center of the borehole, while the fracture zone averages 20 borehole radii away and extends to 50 bore hole radii away. Figure 2.22 illustrates the image of mechanism of burden movement.

In the vicinity of free surfaces, such as the ground surface or a mining bench face, an enhancement of the fracture pattern occurs. This is caused by the transition of the radial component from a compressive to a tensile pulse at the free face as the wave is reflected. The interaction of all wave forms causes intense fracturing within the rock mass between the borehole and the free surfaces. Multiple reflections of outgoing and reflected waves occur while fracturing takes place, dictating flow initiation sites. The resulting fragmentation is highly dependent on geological discontinuities.

In competent dense rock, excellent fragmentation occurs when using explosives that produce high shock forces. Nitro Glycerin -based explosives and highly sensitized blasting agents work well in these rocks.(Porter and Fairhurst,1970[10] /Langefors and Kihlstrom, 1978[10])

2.6.1 Effect of Gas Pressure

Subsequent to detonation, gas products are formed, internally pressurizing the borehole and adjacent cracks. It has been shown that these pressures, often referred to as borehole pressures, are sufficiently high to extend radial cracks while others believe these pressures promote only heaving. Heaving assists in muckpile placement.

In general, explosives formulated with nitrates of ammonium or sodium produce large volumes gas contributing to good heaving and throwing. Their use in well-bedded and jointed material such as sedimentary rock or highly altered ore, promote good fragmentation.

2.6.2 Effects of Geology on Blasting

Rock properties that influence blasting results are strength, density, sonic velocity, and structure. Rock structures are defined using the frequency and orientation of bedding planes, joints, and other naturally occurring fractures. Characteristic impedance, which is the product of density and velocity, is useful for matching an explosive to the intact specimen properties. Knowing the density and wave velocity of a rock, one selects an explosive with a similar impedance value. Often such decisions must also consider the effects of fracture frequency defining the competency of a rock. The selection of explosive loading quantities and explosive type can be guided by rock-mass fracture data.(Porter and Fairhurst,1970[10] /Langefors and Kihlstrom, 1978[10])

CHAPTER 3 - METHDOLOGY

3. METHDOLOGY

This chapter is mainly focused on the methodology and discussion on blasting performance, fragmentation analysis, calculation of mean fragmentation and physical properties of rocks.

3.1 Blasting Performance, Fragmentation Analysis, Calculation of Mean Fragmentation And Rock Properties

This chapter will describe the methodology which was adopted to perform the blasting tests, method of data recording, methodology which is presently used to calculate fragmentation by the Kuz-Ram model and the physical calculation of mean fragmentation by using the manual methodology.

3.1.1. Blasting Performance Analysis

The aim of this section of the thesis is to summarize, perform , study and compare the performance of both Water Gel and Emulsion explosives by analysis of the ground vibration and the blast air over pressure which was performed in the same site using identical parameters for each couple of blasts as follows:

- Two days were selected for the test blasts ,
- Blasting tests were all performed at one single site in order to maintain equal parameters other than the type of Explosive,
- Six blasting tests were performed on the first day and four blasting tests were performed on the other day,
- Both days the adjacent holes were filled with Water Gel and emulsion explosives while keeping all other parameters constant with idea of performing an accurate comparison.
- The second day same locations were selected, thereby maintaining all other parameters, expect the type of Explosives the same as the earlier day. The holes which were filled with Emulsion Explosives was changed to Water Gel explosives and vise versa and the idea was to compare the same location with either Water Gel and Emulsion Explosives,
- The resultant readings were recorded by installing two vibration monitors namely Blast Mates which were facilitated by the Geological Survey and Mines Bureau (GSMB) with the assistant of Mining Engineer / Field Officer.

The above blasting tests were carried out at the “Metal Mix Metal Quarry” which is situated in Meepe area of the Colombo District, Hanwella divisional Secretary area and the location of the above site is clearly marked in the Google map that is annexed as figure 7.48

There were five locations selected in the above site and the detail blasting schedule is annexed herewith as Table 3.1.

Table 3.1: Blasting test schedule

Date	location	Phase	Explosives Used	Constant Parameter	Readings
2016-07-15	Identical to phase 8	1	Emulsion	Burden Spacing Type of Explosives Quantity of explosives	Ground Vibration Air Blast Over Pressure Fragmentation distribution
	Identical to phase7	2	Water Gel		
	dentical tophase10	3	Emulsion		
	Iidentical to phase 9	4	Water Gel		
	Idjacent to each other	5	Emulsion		
	Idjacent to each other	6	Water Gel		
2016-08-05	Identical to phase 2	7	Emulsion		
	Identical to phase 1	8	Water Gel		
	Identical to phase 4	9	Emulsion		
	Identical to phase 3	10	Water Gel		

3.1.2. Fragmentation Analysis and Calculation of Mean Fragmentation

Calculation of mean Fragmentation was performed by

3.1.2.1.Using a manual methodology

3.1.2.2. Methodology which is being presently used to calculate mean fragmentation using Kuz Ram model.

3.1.2.1 Calculation of Fragmentation by Using a Manual Methodology

The fragmentation analysis was carried out by the following manual procedure. The test blasting was performed at the end of the quarry face and the production rubble fell into a cleared zone which was about 20 m below the face and was distributed on the cleared zone as illustrated in Figure 3.1 taken before the blasts and Figure 3.2 taken after the blasts.

Figures 3.1 Image of cleared zone before blast

Figures 3.2 Image of cleared zone after blast

As per the image in Figure 3.2 which illustrates the situation after the blast, the following procedure was adopted to perform the fragmentation analysis,

1. The zone in Figure 3.2 was demarcated as per Figure 3.3
2. Eleven zones were demarcated starting from zone A to zone K.
3. These demarcated zones were photographed separately.

4. Grid lines as illustrated below, with identical spacing were developed in all images for easy calculation purpose.
5. Ten areas were randomly selected in each image with grid lines and the following analysis was done to separate rock sizes in the following manner
    - below 5 cm in length,
    - between 5 cm to 10 cm in length,
    - between 10 cm to 20 cm in length
    - Over 20 cm in length.
6. Manual counting for separate sizes of rock was performed and an average calculation was done for each image
7. There after an average calculation was done for all the zones starting from zone A to zone K.
8. This average was considered the fragmentation analysis.

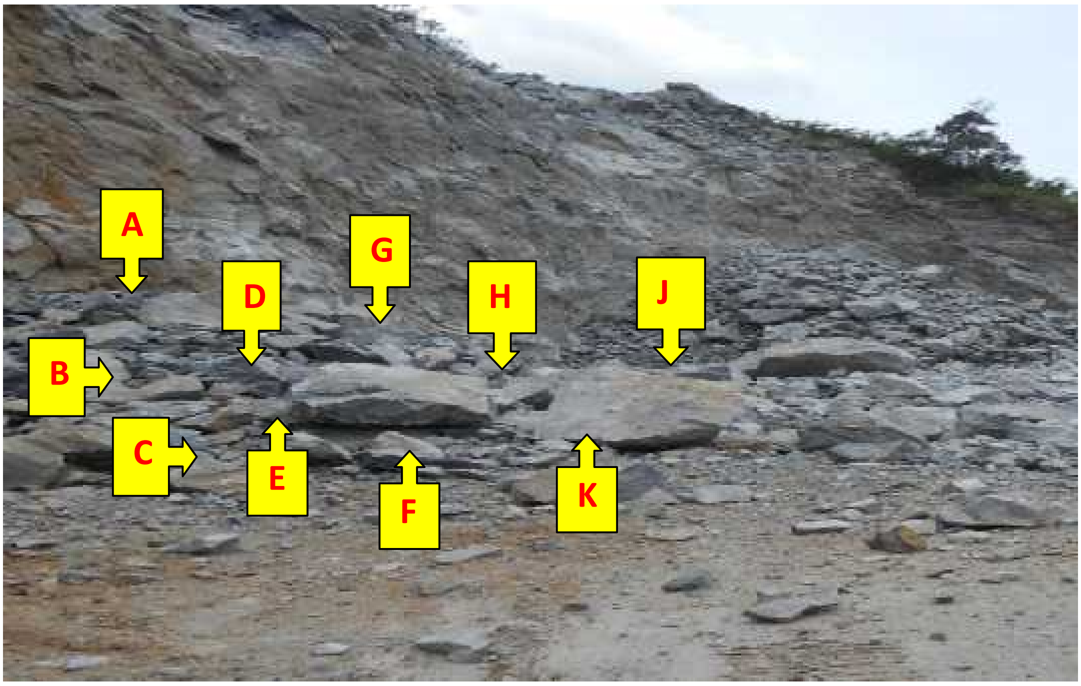

Figure 3.3: Demarcation of zones A to K

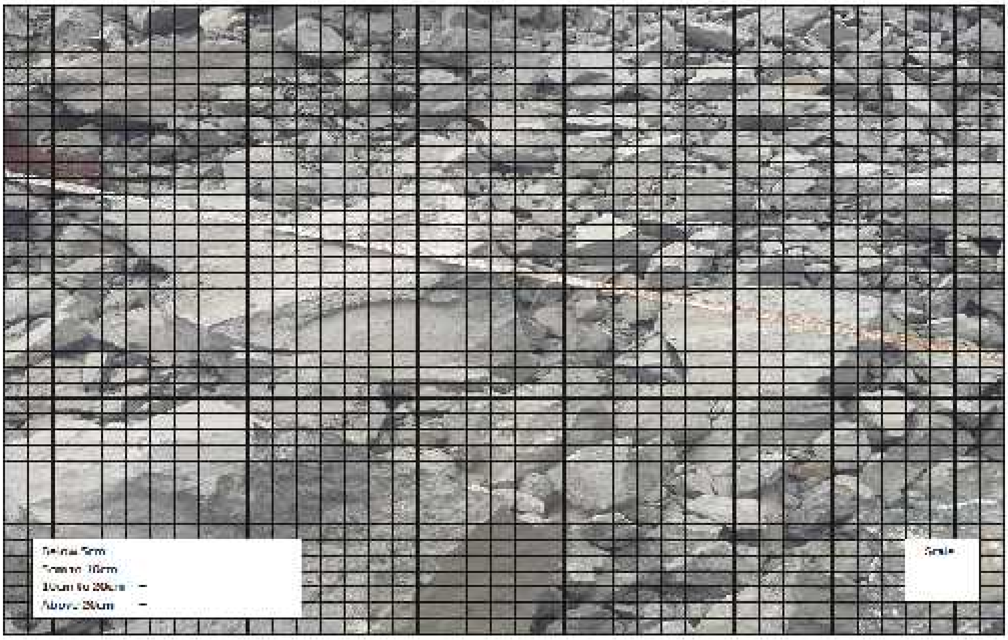

Figure 3.4: Grid diagram used to analyze mean fragmentation.

3.1.2.2 Methodology which is Presently used to Calculate Mean Fragmentation usingKuz-Ram model

The Kuz–Ram model is possibly the most widely used approach to estimate fragmentation from blasting, and renewed interest in the field of blast control has brought increased focus on the model. The author reviews the strengths and weaknesses of the model, indicating the limitations, corrections and modifications he has been using, and suggesting how it can best be used. The basic strength of the model lies in its simplicity in terms of the ease of garnering input data, and in its direct linkage between blast design and rock breaking result. The algorithms are easily incorporated into spread sheets, but a problem with this is the danger of incorrect entries. A further danger is the tendency of inexperienced users to push it beyond its proper range of application. Many criticisms and improvements have been suggested over the years, and these have tended to miss the point that the model is less about precision than about guidance. The major modification from the author has been to factor in the effect of precision timing, as is available from electronic delay detonators.

The primary purpose of blasting is to fragment rock, and there are significant rewards for delivering a fragmentation size range that is not only well suited to the mining system it feeds but also minimizes unsalable fractions and enhances the value of what can be sold. Various models have been put forward over the years, attempting to predict the size distribution resulting from particular blast designs.

The approaches fall into two broad camps,

Empirical modeling - which infers finer fragmentation from higher energy input

Mechanistic modeling - which tracks the physics of detonation and the process of energy transfer in well-defined rock for specific blasting layouts, deriving the whole range of blasting results.

The mechanistic approach is intrinsically able to illustrate the effect of individual mechanisms, something beyond purely empirical models. However, it is more difficult to apply from day to day, as it is limited in scale, requires long run times and suffers from the difficulty of collecting adequate data about the detonation, the rock and the end results. It also requires greater or lesser degrees of empiricism, so is not necessarily more accurate. For all practical purposes, the empirical models are the ones used for daily blast design, and the present author published a scheme as the Kuz– Ram model in the 1980s

The adapted Kuznetsov equation,

$$\mathbf{X(^{m}) = AK^{-0.8}Q^{1/6}\left(\frac{115}{RWS}\right)^{19/20}} \ldots\ldots\ldots\ldots\ldots\ (03)$$

Where,

$X(^{m})$ = mean particle size, cm

A = rock factor[varying between 0.8 and 22, depending on hardness and structure [this is a critical parameter and its derivation is given in equation(4)]

K = powder factor, kg explosive per cubic meter of rock

Q = mass of explosive in the hole, kg

RWS = weight strength relative to ANFO, 115 being the RWS of TNT.

Rock factor - (A)

It is always difficult to estimate the real effect of geology, but the following routine addresses some of the major issues in arriving at the single rock factor A, defined as,

$$\mathbf{A = 0.06\ (RMD + RDI + HF)} \ldots\ldots\ldots\ldots\ldots\ldots\ (04)$$

Where,

RMD - is the rock mass description,

A number is assigned according to the rock condition:

Powdery / friable` = 10

Massive formation (joints further apart than blast hole) = 50

RDI - is the rock density influence

HF - is the hardness factor, the figures for these parameters are derived as follows.

Derive jointed rock factor (JF) as follows:

$$\mathbf{JF = (JCF \times JPS) + JPA} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(05)$$

Where,

JCF is the joint condition factor

JPS is the joint plane spacing factor

JPA is the joint plane angle factor.

Joint condition factor (JCF)

Tight joints	1.0
Relaxed joints	1.5
Gouge-filled joints	2.0

Vertical joint plane spacing factor (JPS)

This factor is partly related to the absolute joint spacing, and partly to the ratio of spacing to drilling pattern, expressed as the reduced pattern,

$$\mathbf{P = (B \times S)^{0.5}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(06)$$

Where,

B and S are burden and spacing

The values of JPS are as follows for the joint spacing ranges:

Joint spacing < 0.1 m,

JPS = 10 (because fine fragmentation will result from close joints)

Joint spacing = 0.1–0.3 m,

JPS = 20 (because unholed blocks are becoming plentiful and large)

Joint spacing = 0.3 m to 95% of P,

JPS = 80 (because some very large blocks are likely to be left)

Joint spacing > P, 50 (because all blocks will be intersected).

Clearly, if the joint spacing and the reduced pattern are both less than 0.3 m, or if P is less than 1 m, then this algorithm could produce strange results. In the original derivation, the index was linked to the maximum defined oversize dimension, but this is clearly not an appropriate input and has been omitted.

3.1.3.Discuss Rock Properties

Further to ascertain the following properties, rock samples collected from the site will be tested at the Moratuwa University laboratory to analyze,

Aggregate Impact Value Aggregate Impact Value - AIV
Los Angeles Abrasion Value - LAAV

3.1.3.1. Determination of Aggregate Impact Value - AIV

Apparatus

(i) A testing machine weighing 45 to 60 kg and having a metal base with a painted lower surface of not less than cm in diameter. It is supported on level and plane concrete floor of minimum 45 cm thickness. The machine should also have provisions for fixing its base.

(ii) A cylindrical steel cup of internal diameter 102 mm, depth 50 mm and minimum thickness 6.3mm.

(iii) A metal hammer or tup weighing 13.5 to 14.0 kg the lower end being cylindrical in shape, 50 mm long, 100.0 mm in diameter, with a 2 mm chamfer at the lower edge and case hardened. The hammer should slide freely between vertical guides and be concentric with the cup. Free fall of hammer should be within 380±5 mm.

(iv) A cylindrical metal measure having internal diameter 75 mm and depth 50 mm for measuring aggregates.

(v) Tamping rod 10 mm in diameter and 230 mm long, rounded at one end.

(vi) A balance of capacity not less than 500g, readable and accurate up to 0.1 g.

Theory

The property of a material to resist impact is known as toughness. Due to movement of vehicles on the road the aggregates are subjected to impact resulting in their breaking down into smaller pieces. The aggregates should therefore have sufficient toughness to resist their disintegration due to impact. This characteristic is measured by impact value test. The aggregate impact value is a measure of resistance to sudden impact or shock, which may differ from its resistance to gradually applied compressive load.

Procedure

The test sample consists of aggregates sized 10.0 mm 12.5 mm. Aggregates may be dried by heating at 100-110° C for a period of 4 hours and cooled.

(i) Sieve the material through 12.5 mm and 10.0mm IS sieves. The aggregates passing through 12.5mm sieve and retained on 10.0mm sieve comprises the test tamping rod.

(ii) Pour the aggregates to fill about just 1/3 rd depth of measuring cylinder.

(iii) Compact the material by giving 25 gentle blows with the rounded end of the tamping rod.

(iv) Add two more layers in similar manner, so that cylinder is full.

(v) Strike off the surplus aggregates.

(vi)Determine the net weight of the aggregates to the nearest gram (W).

(vii) Bring the impact machine to rest without wedging or packing up on the level plate, block or floor, so that it is rigid and the hammer guide columns are vertical.

(viii) Fix the cup firmly in position on the base of machine and place whole of the test sample in it and compact by giving 25 gentle strokes with tamping rod.

(ix) Raise the hammer until its lower face is 380 mm above the surface of aggregate sample in the cup and allow it to fall freely on the aggregate sample. Give 15 such blows at an interval of not less than one second between successive falls.

(x) Remove the crushed aggregate from the cup and sieve it through 2.36 mm IS sieves until no further significant amount passes in one minute. Weigh the fraction passing the sieve to an accuracy of 1 gm. Also, weigh the fraction retained in the sieve.

Compute the aggregate impact value. The mean of two observations, rounded to nearest whole number is reported as the Aggregate Impact Value.

3.2.3.2 Determination of Los Angeles Abrasion Value - LAAV

Apparatus

Figure 3.5: Image of Los Angeles Abrasion Machine and steel balls used

(i) Los Angeles Machine

Los Angeles Machine (Figure 3.5) consists of a hollow steel cylinder, closed at both the ends with an internal diameter of 700 mm and length 500 mm and capable of rotating about its horizontal axis. A removable steel shaft projecting radially 88 mm into cylinder and extending full length (i.e.500 mm) is mounted firmly on the interior of cylinder. The shelf is placed at a distance 1250 mm minimum from the opening in the direction of rotation.

(ii) Abrasive charge

Cast iron or steel balls (Figure 3.5) approximately 48mm in diameter and each weighing between 390 to 445g; six to twelve balls are required.

(iii) Sieve

1.70, 2.36,4.75,6.3,10,12.5,20,25,40,50,63,80 mm IS Sieves.

(iv) Balance of capacity: 5kg or 10kg

(v) Drying oven

(vi) Miscellaneous like tray

Theory

The aggregate used in surface course of the highway pavements are subjected to wearing due to movement of traffic. When vehicles move on the road, the soil particles present between the pneumatic tires and road surface cause abrasion of road aggregates. The steel reamed wheels of animal driven vehicles also cause considerable abrasion of the road surface. Therefore, the road aggregates should be hard enough to resist abrasion. Resistance to abrasion of aggregate is determined in laboratory by Los Angeles test machine. The principle of Los Angeles abrasion test is to produce abrasive action by use of standard steel balls which when mixed with aggregates and rotated in a drum for specific number of revolutions also causes impact on aggregates. The percentage wear of the aggregates due to rubbing with steel balls is determined and is known as Los Angeles Abrasion Value.

Procedure

The test sample consists of clean aggregates dried in oven at 105° – 110°C.

(i) Select the grading to be used in the test such that it conforms to the grading to be used in construction, to the maximum extent possible.

(ii) Take 5 kg of sample for grading A, B, C & D and 10 kg for grading E, F & G.

(iii) Choose the abrasive charge depending on grading of aggregates.

(iv) Place the aggregates and abrasive charge on the cylinder and fix the cover.

(v) Rotate the machine at a speed of 30 – 33 revolutions per minute. The number of revolutions is 500 for grading A, B, C & D and 1000 for grading E, F & G. The machine should be balanced and driven such that there is uniform peripheral speed.

(vi) The machine is stopped after the desired number of revolutions and material is discharged to a tray.

(vii) The entire stone dust is sieved on 1.70 mm IS sieve.

(viii) The material coarser than 1.7mm size is weighed correct to one gram.

Calculation

Original weight of aggregate sample = W_1 g

Weight of aggregate sample retained = W_2 g

Weight passing 1.7mm IS sieve = $W_1 – W_2$ g

Los Angeles Abrasion Value = $(W_1 – W_2) / W_1 \times 100$

CHAPTER4 - RESULTS AND DISSCUSSION

4 RESULTS AND DISSCUSSION

This chapter basically consists of all the tests done and its results performing the comparative study and the fragmentation analysis.

4.1. Results

4.1.1 Ground Vibrations and Air Blast Over Pressure

Table 4.1- Ground Vibrations and Air Blast Over Pressure measurements.

Blast Index	Time of Blast	Quantity of Explosives used per bore hole	Bore hole Depth (m)	Spacing (m)	Burden (m)	Blast Mate Readings			
						Blast mate A		Blast mate B	
						Ground Vibration (m/s)	Air Blast Over pressure (db)	Ground Vibration (m/s)	Air Blast Over pressure (db)
Phase 01	11.53 am	Emulsion 125gms El Det 01unit ANFO 2.10 kgs	3	1.60	1.47	0.399	116.7	0.18	100.0
Phase 02	11.49 am	WaterGel125gms El Det 01unit ANFO 2.10 kgs	3	1.45	1.30	0.59	111.8	2.97	110.5
Phase 03	11.45 am	Emulsion 125 ms El Det 01unit ANFO 2.10 kgs	3	1.50	1.30	0.102	104.2	0.22	100.0
Phase 04	11.56 am	WaterGel125gms El Det 01unit ANFO 2.25 kgs	3	1.50	1.40	0.085	103.5	3.88	120.0
Phase 05	12.09 pm	Emulsion 125gms El Det 01unit ANFO 2.05 kgs	3	1.70	1.40	0.197	110.9	0.22	100.0
Phase 06	12.16 pm	WaterGel125gms El Det 01unit ANFO 2.05 kgs	3	1.50	1.40	0.0794	101.9	1.93	107.0
Phase 07	11.53 am	Emulsion 125 gms El Det 01unit ANFO 2.10 kgs	3	1.50	1.20	0.440	115.4	0.20	94.0

Blast Index	Time of Blast	Quantity of Explosives used per bore hole	Bore hole Depth (m)	Spacing (m)	Burden (m)	Blast Mate Readings			
						Blast mate A		Blast mate B	
						Ground Vibration (m/s)	Air Blast Over pressure (db)	Ground Vibration (m/s)	Air Blast Over pressure (db)
Phase 08	11.49 am	WaterGel25gms El Det 01unit ANFO 2.10 kgs	3	1.40	1.20	0.912	103.5	0.26	102.8
Phase 09	11.45 am	Emulsion125gms El Det 01unit ANFO 2.10 kgs	3	1.50	1.20	0.87	102.8	6.49	119.1
Phase 10	11.56 am	WaterGel125gms El Det 01unit ANFO 2.25 kgs	3	1.50	1.20	0.446	115.7	5.02	116.4

4.1.2 Comparison of Air Blast Over Pressure and Ground Vibration readings with respect to Water Gel and Emulsion Explosives

Table 4.2: Comparison of Air Blast Over Pressure and Ground Vibration with respect to Water Gel and Emulsion Explosives

Phase	Type of Explosive	Blast Mate Readings			
		Blast mate A		Blast mate B	
		Ground Vibration (m/s)	Air Blast Over pressure (db)	Ground Vibration (m/s)	Air Blast Over pressure (db)
01	**Emulsion**	0.399	116.7	0.18	100.0
02	**Water Gel**	0.59	111.8	2.97	110.5
03	**Emulsion**	0.102	104.2	0.22	100.0
04	**Water Gel**	0.085	103.5	3.88	120.0
05	**Emulsion**	0.197	110.9	0.22	100.0
06	**Water Gel**	0.0794	101.9	1.93	107.0
07	**Emulsion**	0.440	115.4	0.20	94.0
08	**Water Gel**	0.912	103.5	0.26	102.8
09	**Emulsion**	0.87	102.8	6.49	119.1
10	**Water Gel**	0.446	115.7	5.02	116.4

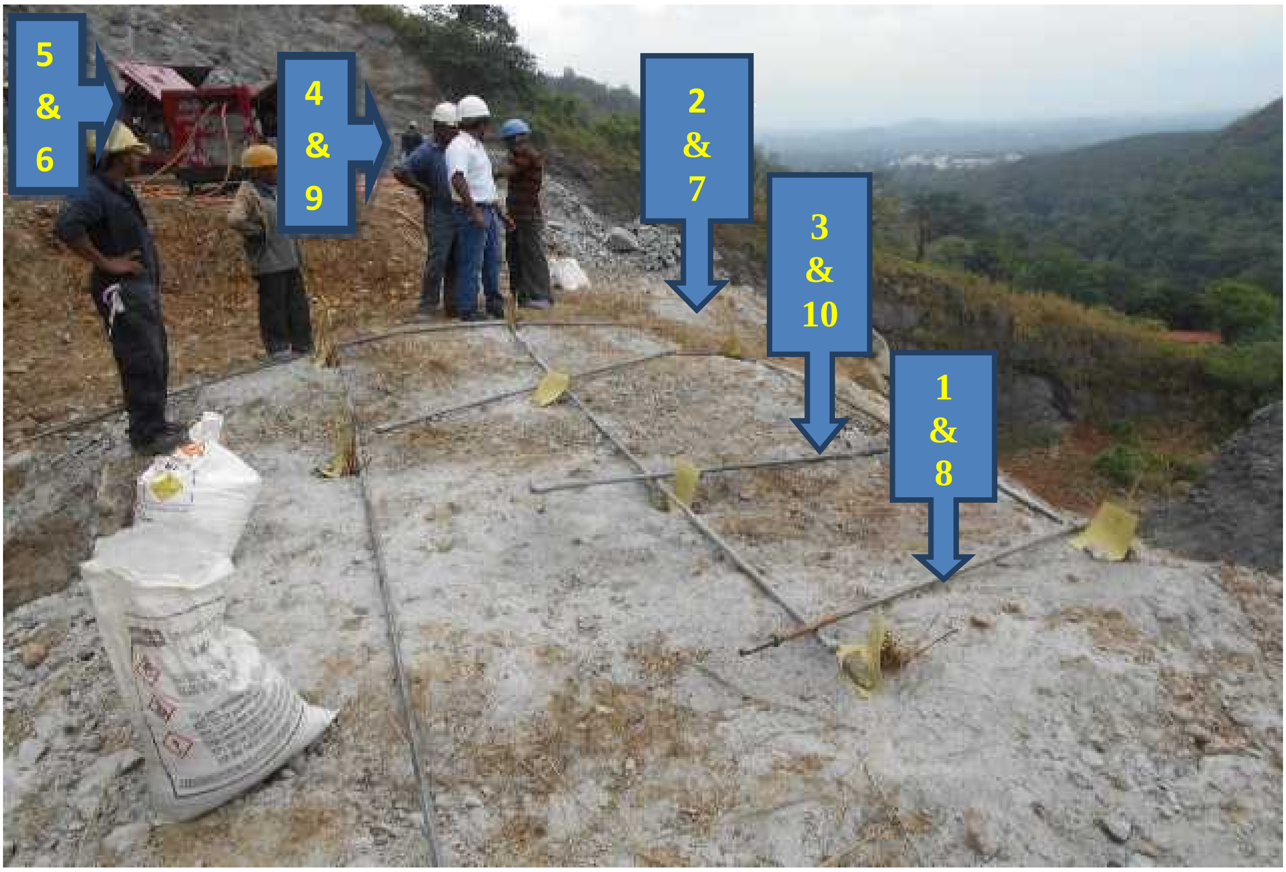

Figure 4.1 :Demarcation of blasting phases

4.1.3 Detailed Study on Selected Properties of Emulsion Explosives

Two local institutions were granted authority by the Ministry of Defence to manufacture samples of emulsion explosives which were to be used for test blasting in open cast and underground blasting in the selected locations island wide. The samples of Emulsion explosives were distributed to the Assistant Controllers of Explosives in Anuradahpura, Colombo , Kalutara , Gampaha, Kandy , Kurunegala and Kegalle districts to conduct blasting tests according to the under mentioned criteria's. Blasting tests were done in each district with the participation of the relevant Assistant Controllers , project owners and the company blasting foreman's .

The request letter sent to the Assistant Controllers from Ministry Defence bears reference MOD/CS/08/EX/02/EMULSION PROJ Dated 2015-11-11 in which the following required seven observations were specified as per annexure in table 7.11

(a) Air over pressure	High / Low / No difference
(b) Ground Vibration	High / Low / No difference
(c) initiated coupled with safety fuse and blasting powder	High / Low / No difference

(d) Fly rocks High / Low / No difference High / Low / No difference

(e) Production High / Low / No difference High / Low / No difference

(f) Fragmentation High / Low / No difference High / Low / No difference

(g) User friendly level High / Low / No difference High / Low / No difference

Reports were received from all the above mentioned districts and the final report received from the Kandy district is annexed as table 7.12.The total report received from all the seven districts contained 80 pages which was summarized and the net result is annexed as table 4.3,

Table 4.3: Comparative study on Ground Vibration, Air Blast Over Pressure, fly rocks, production and fragmentation properties on the application of Emulsion explosive district wise

District	No of Tests	GV when compared with Water Gel Explosives	ABOP when compared with Water Gel Explosives	Firing when coupled with safety fuse and blasting powder	Fly rocks when compared with Water Gel Explosives	Production when compared with Water Gel Explosives	Fragmentation when compared with Water Gel Explosives	User friendliness when compared with Water Gel Explosives
Anuradhapura	07	No Difference	No Difference	Successful	No Difference	No Difference	High	Better
Colombo	5	High	No Difference	Not applicable	High	No Difference	No Difference	Better
Kalutara	10	No Difference	No Difference	Not applicable	No Difference	No Difference	High	Better
Gampaha	17	No Difference	No Difference	Successful	No Difference	No Difference	No Difference	Better
Kandy	15	No Difference	No Difference	Not Clear	Mixed Comments	No Difference	No Difference	Mixed Comments
Kurunegala	01	No Difference	Low	Successful	lower	High	High	Better
Kegalle	01	No comment	No comment	Not Applicable	No comments	High	High	Better
Committee	01	No comment	No comment	Successful	lower	High	High	No comments
Final Evaluation	**57**	**No difference when compared with Water Gel Explosives**	**No difference when compared with Water Gel Explosives**	**Successful**	**Low when compared with Water Gel Explosives**	**High when compared with Water Gel Explosives**	**High when compared with Water Gel Explosives**	**Better when compared with Water Gel Explosives**

Note: The blasting tests above were performed by the respective quarry owners in IML B and C categories under the instructions of the Assistant Controllers of the districts.

4.2 Calculation of Aggregate Impact and Los Angeles Abrasion Values

Table 4.4- Calculated Aggregate Impact Value as per laboratory test – AIV

LAAV	05 kg
Aggregate	3030 gms
Dust	1940 gms

Table 4.5- Calculated Los Angeles Abrasion Value as per laboratory test- LAAV

LAAV	600 gms
Aggregate	471 gms
Dust	127 gms

Rock Sample 11 inches - 35 KN

4.3 Calculation of Mean Fragmentation using the Manual Method

This was performed on 05th of August, 2016 immediately after the test blasts in phases 7 to 10 as described earlier in chapter 3.1.2.1. The output which was collected in the cleared zone just below the blasting site was demarcated and the calculation of the mean fragmentation was done manually.

Separate calculation of mean fragmentation for zones A to K will appear in pages 65 to 74

The readings of Ground Vibration and Air Blast Over Pressure readings will appear in

Table 4.1

The comparison of Air Blast Over Pressure and Ground Vibration with respect to Water Gel and Emulsion Explosives will appear in Table 4.2

4.3.1 Analysis of Samples Using Grid Diagrams for Zones A To K

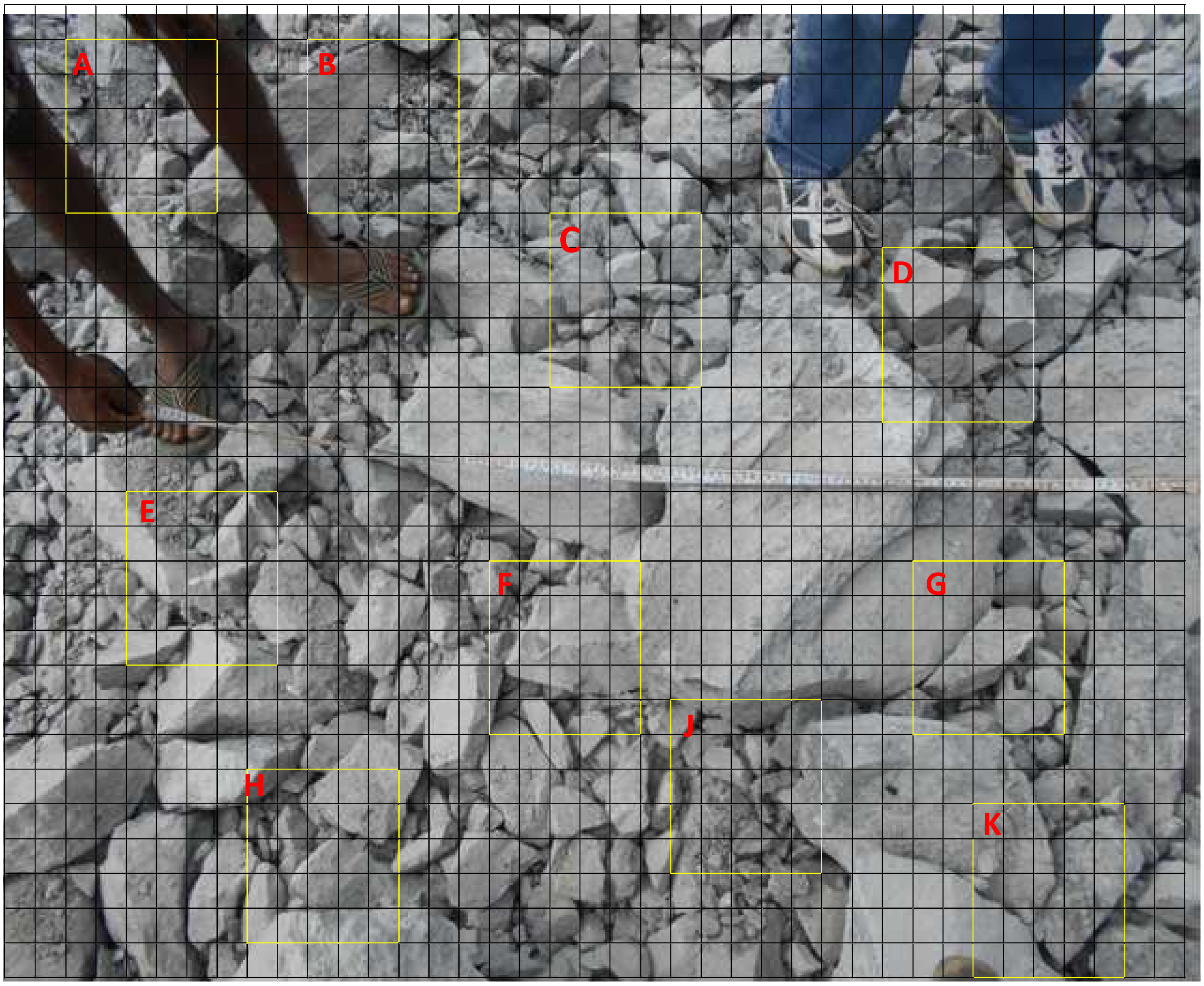

Figure 4.2 - Analysis of samples using grid diagram in zone - A Scale 1 square : 25 cm^2

Table 4.6 - Fragmentation analysis data in Zone A

Area	Below 5 cm	5 cm to 10 cm	10 cm to 20 cm	over 20 cm
A	10	6	1	1
B	20	4	2	1
C	12	5	1	2
D	08	4	3	2
E	18	5	4	2
F	08	4	0	2
G	10	1	1	1
H	08	4	2	1
J	14	2	0	2
K	08	1	1	3
Average	11.6	3.6	1.5	1.7

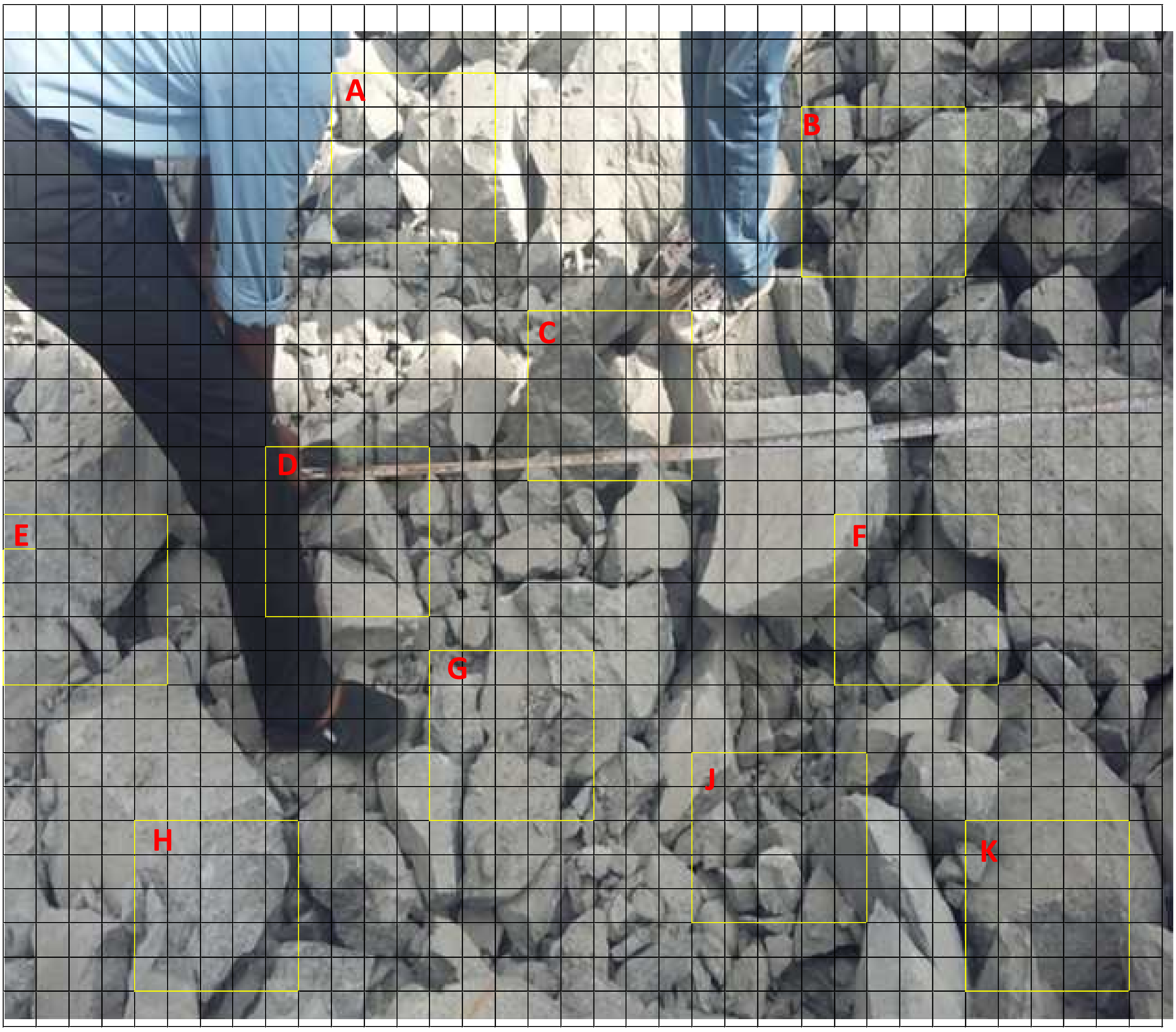

Figure 4.3 - Analysis of samples using grid diagram in zone - B Scale 1 square : 25 cm^2

Table 4.7 - Fragmentation analysis data in Zone B

Area	Below 5 cm	5 cm to 10 cm	10 cm to 20 cm	over 20 cm
A	6	4	2	1
B	5	3	1	1
C	2	2	1	3
D	2	4	0	4
E	4	0	1	3
F	8	4	1	2
G	12	2	2	3
H	0	2	0	2
J	15	4	3	2
K	1	0	1	1
Average	5.5	2.5	1.2	2.0

Figure 4.4- Analysis of samples in zone - C Scale 1 square : 16 cm^2

Table 4.8 - Fragmentation analysis data in Zone C

Area	Below 5 cm	5 cm to 10 cm	10 cm to 20 cm	over 20 cm
A	8	4	2	2
B	10	5	2	2
C	12	1	0	3
D	3	2	0	3
E	16	2	2	1
F	1	3	2	2
G	4	2	2	1
H	12	2	1	1
J	16	4	1	2
K	0	0	1	3
Average	8.2	2.5	1.4	2.0

Figure 4.5. -Analysis of samples using grid image in zone - D Scale 1 square : 25 cm^2

Table 4.9- Fragmentation analysis data in Zone D

Area	Below 5 cm	5 cm to 10 cm	10 cm to 20 cm	over 20 cm
A	0	3	1	3
B	8	4	0	3
C	0	1	1	1
D	4	1	0	3
E	2	2	2	3
F	0	2	1	3
G	6	2	1	3
H	0	0	1	2
J	10	0	0	4
K	8	0	0	4
Average	3.8	1.5	0.7	2.9

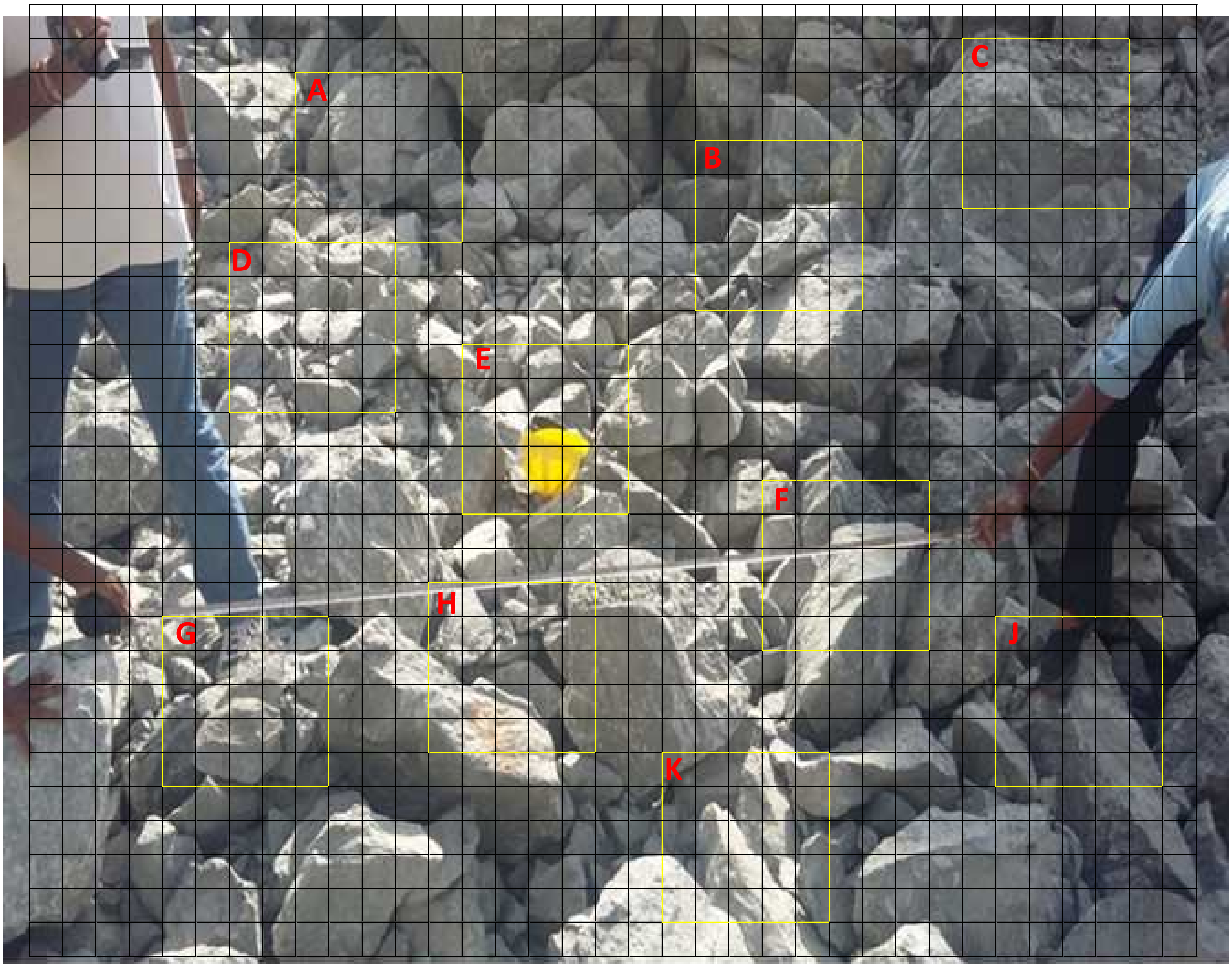

Figure 4.6 - analysis of samples using grid image in zone - E scale 1 square : 36 cm^2

Table 4.10 - fragmentation analysis data in zone E

Area	Below 5 cm	5 cm to 10 cm	10 cm to 20 cm	over 20 cm
A	6	4	2	2
B	2	7	2	3
C	24	1	0	1
D	8	4	8	0
E	8	4	4	2
F	0	1	3	3
G	2	4	3	2
H	12	4	2	2
J	6	0	2	2
K	0	2	2	4
Average	6.8	3.1	2.8	2.1

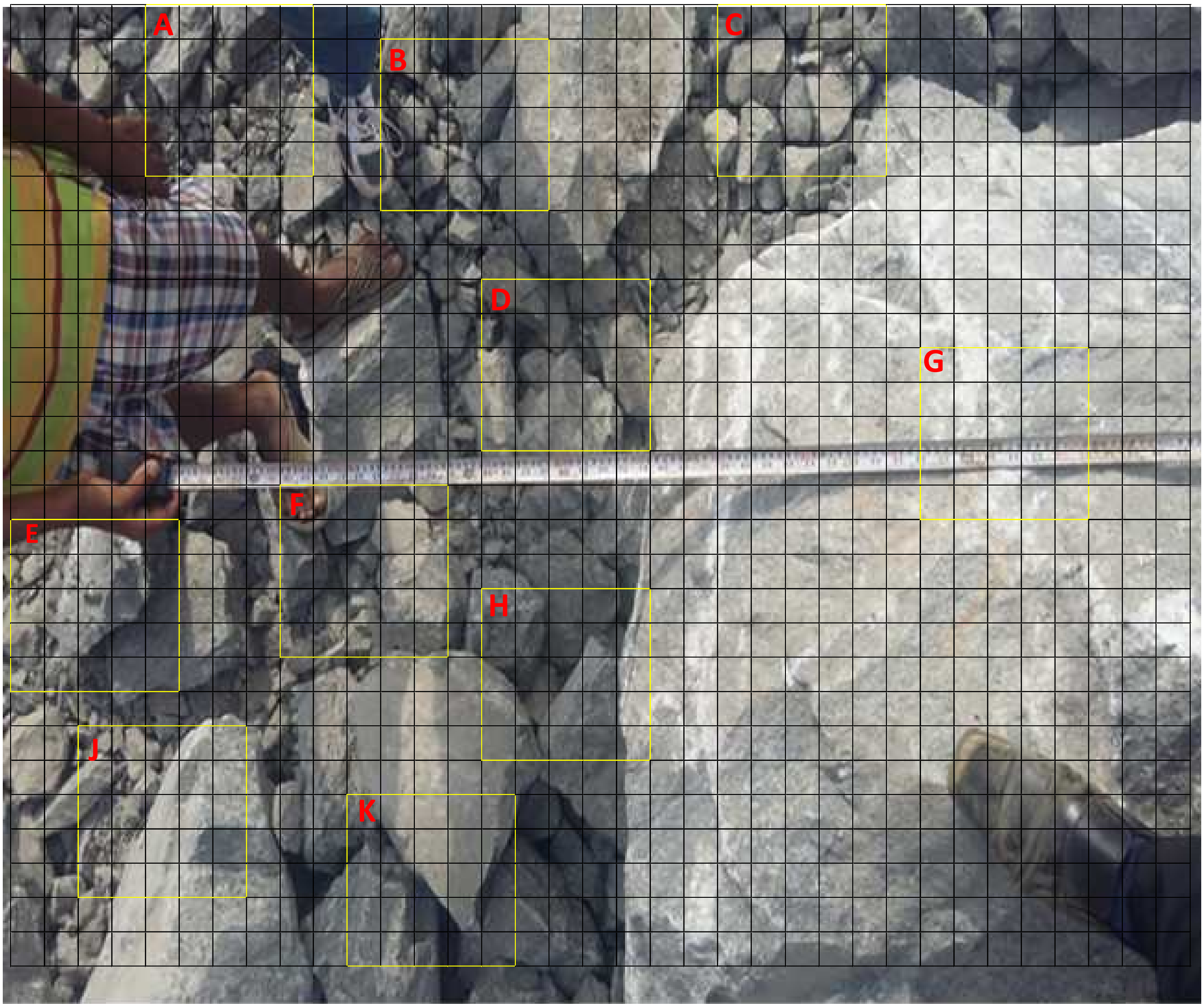

Figure 4.7 - Analysis of samples using grid image in zone - F Scale 1 square : 25 cm^2

Table 4.11 - Fragmentation analysis data in Zone F

Area	Below 5 cm	5 cm to 10 cm	10 cm to 20 cm	over 20 cm
A	24	8	3	0
B	10	4	3	1
C	8	8	3	1
D	10	3	3	1
E	20	0	0	2
F	12	5	1	3
G	0	0	0	1
H	0	0	1	5
J	16	2	1	1
K	0	0	0	4
Average	10.0	3.0	1.5	1.9

Figure 4.8 - analysis of samples using grid image in zone - G Scale 1 square : 100 cm^2

Table 4.12 - fragmentation analysis data in Zone G

Area	Below 5 cm	5 cm to 10 cm	10 cm to 20 cm	over 20 cm
A	10	6	4	3
B	16	0	4	5
C	0	4	3	5
D	0	0	2	8
E	0	0	0	5
F	0	0	1	5
G	0	0	2	6
H	0	0	3	6
J	0	0	2	7
K	0	0	4	4
Average	2.6	1.0	2.5	5.3

Figure 4.9- Analysis of samples using grid image in zone –H   Scale 1 square : 100 cm^2

Table 4.13- Fragmentation analysis data in Zone H

Area	Below 5 cm	5 cm to 10 cm	10 cm to 20 cm	over 20 cm
A	30	12	4	1
B	36	16	4	2
C	24	12	6	4
D	0	0	2	8
E	16	10	6	5
F	0	0	1	6
G	0	0	1	8
H	0	0	2	4
J	0	0	1	8
K	0	0	0	4
Average	10.6	4.0	3.1	5.2

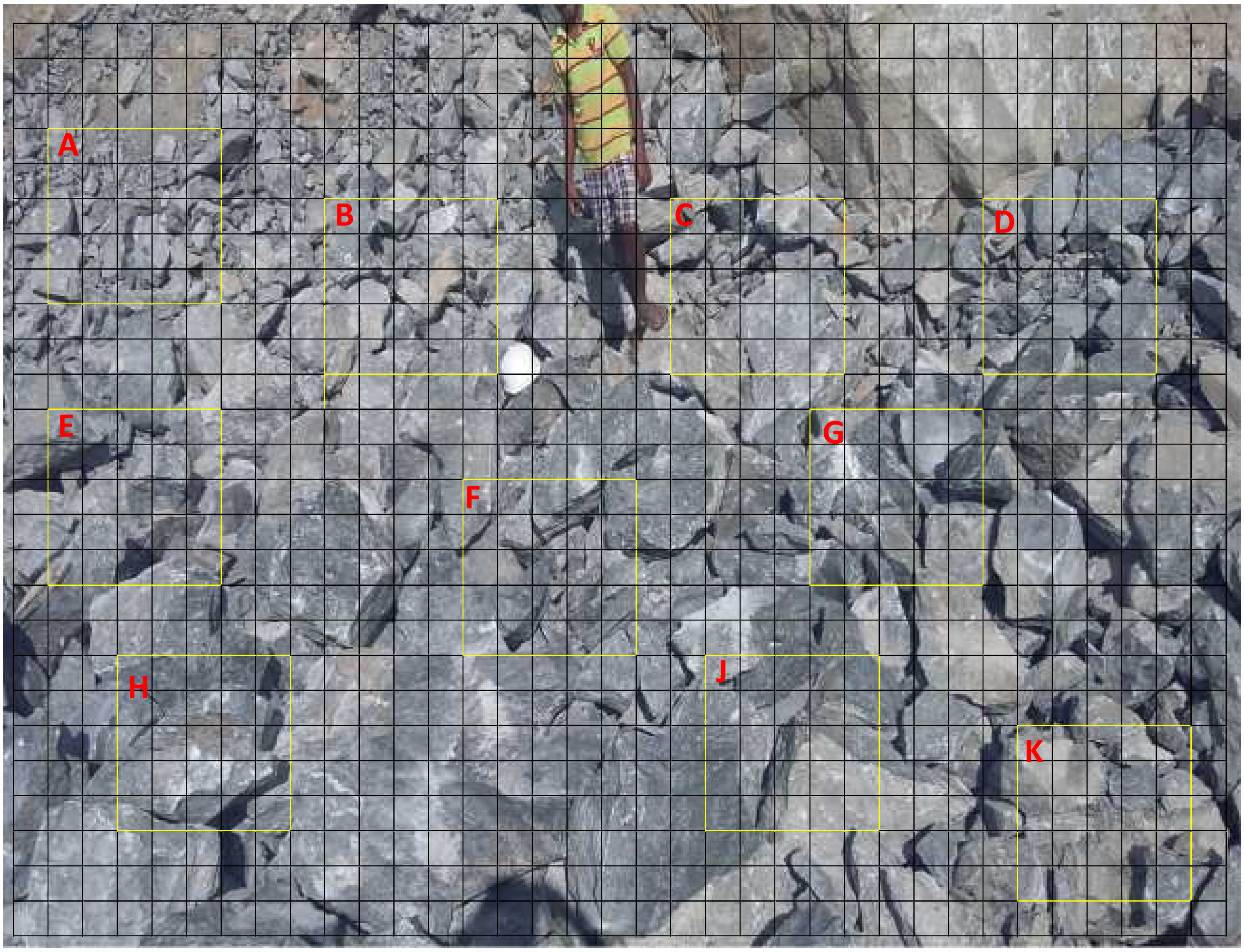

Figure 4.10 - analysis of samples using grid image in zone –J scale 1 square :225cm^2

Table 4.14- fragmentation analysis data in Zone J

Area	Below 5 cm	5 cm to 10 cm	10 cm to 20 cm	over 20 cm
A	20	12	8	6
B	0	0	6	8
C	0	04	12	8
D	16	10	6	8
E	0	0	4	10
F	0	0	2	10
G	0	0	1	9
H	0	0	0	6
J	0	0	0	4
K	24	0	2	8
Average	6.0	2.6	4.1	7.6

Figure 4.11 –Analysis of samples using grid image in zone - K Scale 1 square : 144 cm^2

Table 4.15 - Fragmentation analysis data in Zone- K

Area	Below 5 cm	5 cm to 10 cm	10 cm to 20 cm	over 20 cm
A	0	8	1	6
B	1	0	3	4
C	20	8	3	6
D	0	0	3	7
E	0	2	4	4
F	10	4	3	5
G	8	4	6	6
H	6	0	2	8
Average	4.5	2.6	2.5	4.6

4.3.2: Results of Fragmentation Distribution

Table 4.16: Summary of fragmentation analysis of Emulsion and Water Gel explosives:

Zone	Samples 0-5 cm	Samples 5-10 cm	Samples 10-20 cm	Samples over 20cm
A	11.6	3.6	1.5	1.7
B	5.5	2.5	1.2	2.0
C	8.2	2.5	1.4	2.0
D	3.8	1.5	0.7	2.9
E	6.8	3.1	2.8	2.1
F	10.0	3.0	1.5	1.9
G	2.6	1.0	2.5	5.3
H	10.6	4.0	3.1	5.2
J	6.0	2.6	4.1	7.6
K	4.5	2.6	2.5	4.6
TOTAL	69.6	26.4	21.3	35.3
AVERAGE	6.96	2.64	2.13	3.53
%	**45.6 %**	**17.3 %**	**13.9 %**	**23.2 %**
Fragmentation distribution pattern **Below 10 cm 63 %** **Over 10 cm 37%**				

passing through %

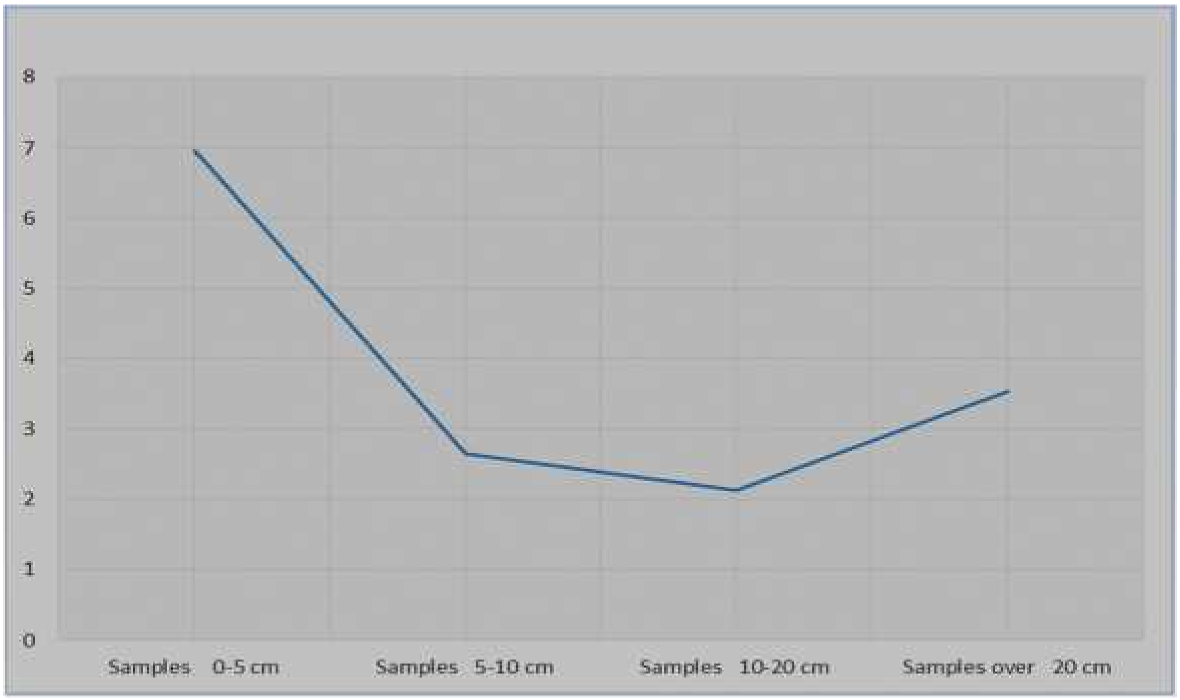

Figure 4.12: Fragmentation analysis curve of Emulsion and Water Gel explosives:

Figure 4.13: Fragmentation Analysis Curve of Water Gel Explosives

The following analysis was performed at the same quarry site where the above blasting tests were performed.

4.4 Discussion

Chapter 1, the introduction part of this thesis describes that Dynamite was the prime high explosives that was used during the 16th to the 21st centuries just before invention of the Water Gel and Emulsion explosives in the 21st century. Dynamite was highly accepted by the past miners due to its very high shattering power, resulting in more yields over the negative impact on environment and health was not considered a prime factor.

Thereafter, during the last couple of decades, the world attention was aimed more towards the environment conversation and green technologies which have a direct result for the switching over from Dynamite to slurry explosives. There are other factors also involved for this switch over and specially the advantages of using Slurry Explosives and disadvantages of using Dynamite have been discussed earlier in chapter 2.5.2 and 2.5.4 respectively. Some countries have totally ban the use of dynamite and most of the most of the other countries have switched over to the use of slurries.

In Sri Lanka also Dynamite was very popular until the GOSL taking into consideration the national security during the period years 2011/2012 initiated the restriction of Dynamite. Parallel to this in year 2010 local manufacture of water gel explosives as a substitute for Dynamite was approved and the samples were available for testing in year 2011.Although, initially there was a very high objections by the quarry owners on the application of the new product but within a period of about one year users began to accept the Water Gel explosives. The success rate was so high the GOSL was unable to distribute the remaining stocks of Dynamite imported in year 2011 with the users opting for water gel and this resulted in about 30 metric tons of Dynamite which had to be destroyed recently.

The following major factors were the main causes for discontinuation of dynamite usage,

- The negative impact on the environment, a large amount of complaints received by the relevant authorities and a result of some metal quarries closing down,
- The price difference and the cost of Water Gel explosives being much less than the Dynamite,
- The country was in the midst of the Eelam war and Ministry of Defence and the relevant Security establishments was in the opinion that Dynamite can be used for insurgent activities
- Dynamite was an imported commodity which resulted in short supply if procurement procedures fail whereas Water Gel and Emulsion explosives are manufactured locally.

A part of the aim of this thesis was to do a comparative study of all high explosives that are applicable in Sri Lankan quarry industry and WaterGel and Emulsion explosives were considered, Dynamite was omitted from the study for two reasons.

- ➢ The unofficial ban and restriction on Dynamite which is effective from 2012 onwards,

- ➢ The last consignment of Dynamite was imported into the country in 2011 and thereby the shelf life has expired,

Comparative studies and blasting tests were performed using only locally produced Water-gel explosives and Emulsion explosives samples.

Table 4.11 illustrates the comparative study that was performed using Water Gel and Emulsion explosives under similar parameters. Your kind attention is directed on the summary of the above test blast and the following observations were received.

Test blasts in phases 1, 2, 3, 4, 5 and 6 were performed on the first day one where 1, 3 and 5 phases were charged using Emulsion explosives and the rest phases 2, 4 and 6 were charged using Water Gel explosives. Test blasts for phases 7, 8, 9 and 10 were performed the next day with phases 7 and 9 being charged with Emulsion explosives and 8 and 10 charged with Water Gel explosives. This sequence of testing was performed in a way that phases 1 and 8, 2 and 7, 3 and 10, 4 and 9, 5 and 6 were performed in the identical location, thereby keeping all parameters equal but varying the type of explosive only. This methodology will create an accurate comparison between the two explosives. This charging methodology created another way of comparison because adjacent holes were again charged with different kind of explosives thereby creating another system to compare between adjacent holes which were 1 and 2, 1 and 4, 2 and 3, 7 and 8, 8 and 9, 7 and 10. This chapter will discuss the comparison in both these ways and thereby enabling to get an accurate prediction.

(a) Blasting test results recorded in the blast mates reveals that phase1 which used emulsion explosives recorded less vibration than phase 8 where water gel explosives were used. In the case of air over pressure in the use of Emulsion explosives, blast mate A recorded higher value and the blast mate B recorded a lesser value.

Table 4.17 Comparison of GV and ABOV for Water Gel and Emulsion Explosives in phases 1 and 8

Phase	**Type of Explosive**	**Blast Mate Readings**			
		Blast mate A		**Blast mate B**	
		Ground Vibration (m/s)	**Air Blast Over Pressure (db)**	**Ground Vibration (m/s)**	**Air Blast Over Pressure (db)**
01	**Emulsion**	0.399	116.7	0.18	100.0
08	Water Gel	0.912	103.5	0.26	102.8

(b) Similar results were obtained in the blasting test results recorded in the blast mates reveals that phase 7 which used Emulsion explosives recorded less vibration and air over pressure than phase 2where Water Gel explosives were used

Table 4.18 Comparison of GV and ABOV for Water Gel and Emulsion Explosives in phases 2 and 7

Phase	**Type of Explosive**	**Blast Mate Readings**			
		Blast mate A		**Blast mate B**	
		Ground Vibration (m/s)	**Air Blast Over Pressure (db)**	**Ground Vibration (m/s)**	**Air Blast Over Pressure (db)**
07	**Emulsion**	0.440	115.4	0.20	94.0
02	**Water Gel**	0.59	111.8	2.97	110.5

(c) Similar results were obtained in the blasting test results recorded in the blast mates reveals that phase 3 which used Emulsion explosives recorded less vibration and air over pressure than phase 10 where Water Gel explosives were used.

Table 4.19 Comparison of GV and ABOV for Water Gel and Emulsion Explosives in phases 3 and 10

Phase	**Type of Explosive**	**Blast Mate Readings**			
		Blast mate A		**Blast mate B**	
		Ground Vibration (m/s)	**Air Blast Over Pressure (db)**	**Ground Vibration (m/s)**	**Air Blast Over Pressure (db)**
03	**Emulsion**	0.102	104.2	0.22	100.0
10	**Water Gel**	0.446	115.7	5.02	116.4

(d) Blasting test results recorded in the blast mates were the opposite of the above three and both reading in phase9 which used Emulsion explosives recorded higher vibration and air over pressure than phase 4 where Water Gel explosives were used.

Table 4.20 Comparison of GV and ABOV for Water Gel and Emulsion Explosives in phases 4 and 9

Phase	**Type of Explosive**	**Blast Mate Readings**			
		Blast mate A		**Blast mate B**	
		Ground Vibration (m/s)	**Air Blast Over Pressure (db)**	**Ground Vibration (m/s)**	**Air Blast Over Pressure (db)**
09	**Emulsion**	0.87	102.8	6.49	119.1
04	**Water Gel**	0.085	103.5	3.88	120.0

(e) Blasting test results recorded in the blast mates reveals that phase 5 which used Emulsion explosives recorded high vibration and air over pressure reading than phase 6 where Water Gel explosives were used. This was an entirely different situation when compared with above (a) to (c).

Table 4.21 Comparison of GV and ABOV for Water Gel and Emulsion Explosives in phases 5and 6

Phase	Type of Explosive	Blast Mate Readings			
		Blast mate A		Blast mate B	
		Ground Vibration (m/s)	Air Blast Over Pressure (db)	Ground Vibration (m/s)	Air Blast Over Pressure (db)
05	**Emulsion**	0.197	110.9	0.22	100.0
06	**Water Gel**	0.0794	101.9	1.93	107.0

(f) Similar results were obtained in the blasting test results recorded in the blast mates reveals that phase 1 which used Emulsion explosives recorded less vibration and air over pressure than phase 2 where Water Gel explosives were used.

Table 4.22 Comparison of GV and ABOV for Water Gel and Emulsion Explosives in phases 1 and 2

Phase	Type of Explosive	Blast Mate Readings			
		Blast mate A		Blast mate B	
		Ground Vibration (m/s)	Air Blast Over Pressure (db)	Ground Vibration (m/s)	Air Blast Over Pressure (db)
01	**Emulsion**	0.399	116.7	0.18	100.0
02	**Water Gel**	0.59	111.8	2.97	110.5

(g) Blasting test results recorded in the blast mates reveals hat phase1 which used Emulsion explosives recorded less vibration and air over pressure than phase 2 where Water Gel explosives were used.

Table 4.23 Comparison of GV and ABOV for Water Gel and Emulsion Explosives in phases 3 and 4

Phase	Type of Explosive	Blast Mate Readings			
		Blast mate A		Blast mate B	
		Ground Vibration (m/s)	Air Blast Over Pressure (db)	Ground Vibration (m/s)	Air Blast Over Pressure (db)
01	**Emulsion**	0.399	116.7	0.18	100.0
04	**Water Gel**	0.085	103.5	3.88	120.0

(h) Blasting test results recorded in the blast mates reveals that phase 3 which used Emulsion explosives recorded less vibration and air over pressure than phase 2 where Water Gel explosives were used.

Table 4.24 Comparison of GV and ABOV for Water Gel and Emulsion Explosives in phases 2 and 3

Phase	**Type of Explosive**	**Blast Mate Readings**			
		Blast mate A		**Blast mate B**	
		Ground Vibration (m/s)	**Air Blast Over Pressure (db)**	**Ground Vibration (m/s)**	**Air Blast Over Pressure (db)**
03	**Emulsion**	0.102	104.2	0.22	100.0
02	**Water Gel**	0.59	111.8	2.97	110.5

(j) Blasting test results recorded in the blast mates reveals that phase7 which used Emulsion explosives recorded less vibration and air over pressure than phase 10.

Table 4.25 Comparison of GV and ABOV for Water Gel and Emulsion Explosives in phases 7 and 10

Phase	**Type of Explosive**	**Blast Mate Readings**			
		Blast mate A		**Blast mate B**	
		Ground Vibration (m/s)	**Air Blast Over Pressure (db)**	**Ground Vibration (m/s)**	**Air Blast Over Pressure (db)**
07	**Emulsion**	0.440	115.4	0.20	94.0
10	**Water Gel**	0.446	115.7	5.02	116.4

(k) Blasting test results recorded in the blast mates reveals that phase 9 which used Emulsion explosives recorded less vibration than phase 8.

Table 4.26 Comparison of GV and ABOV for Water Gel and Emulsion Explosives in phases 8 and 9

Phase	**Type of Explosive**	**Blast Mate Readings**			
		Blast mate A		**Blast mate B**	
		Ground Vibration (m/s)	**Air Blast Over Pressure (db)**	**Ground Vibration (m/s)**	**Air Blast Over Pressure (db)**
09	**Emulsion**	0.440	115.4	0.20	94.0
08	Water Gel	0.912	103.5	0.26	102.8

(m) Blasting test results recorded in the blast mates reveals that phase 7 which used Emulsion explosives recorded less vibration than phase 8.

Table 4.27 Comparison of GV and ABOV for Water Gel and Emulsion Explosives in phases 7 and 8

Phase	**Type of Explosive**	**Blast Mate Readings**			
		Blast mate A		**Blast mate B**	
		Ground Vibration (m/s)	**Air Blast Over Pressure (db)**	**Ground Vibration (m/s)**	**Air Blast Over Pressure (db)**
07	**Emulsion**	0.440	115.4	0.20	94.0
08	**Water Gel**	0.912	103.5	0.26	102.8

4.4.1 Overall Analysis:

The tests recorded Twenty Two readings with regard to ground vibration recordings and the overall situation is that in eighteen cases ,recordings show that the ground vibration readings were low in Emulsion explosives and were high in Water gel explosives. There were only four cases which recorded that Water Gel explosives recorded lower readings than Emulsion explosives.

In these four cases only one blast recorded both reading with the less ground vibration for Water Gel explosives and there were two other cases were only one blast mate recorded Water Gel with lower reading and the other blast mate recorded Emulsion explosives with lower reading.

With regard to the air over pressure results same amount of readings were recorded by both the blast mates. The overall tally of recordings with less ground vibration in the air over pressure readings for Emulsion explosives was fifteen and less ground vibration in the air over pressure readings for Water Gel explosives was seven. There were no instances where both the readings in one blast test recorded higher value of air over pressure readings for Water Gel explosives.

The overall analysis is that the percentage of Emulsion explosives recording lower ground vibration than Water Gel was very high as 82%.

The overall analysis is that the percentage of Emulsion explosives recording lower ground vibration than Water Gel was higher with 68 %.

Therefore it can be assumed that the overall situation is that Emulsion explosives record lower ground vibration and air over pressure than the Water Gel explosives.

CHAPTER 5- CONCLUSION

5 CONCLUSION:

The world trend has changed from Dynamite to slurry explosives, and the local quarry industry experienced the transformation of Dynamite to Water Gel explosives. Most of the countries world over had the transformation from Dynamite to Emulsion explosives but the local scenario is different due to the factor that the local manufacture opted to produce Water Gel explosives only. The quarry owners had no option but to get used to Water Gel explosives. The disadvantage of Water Gel explosives was that it could not be used in under water and underground mining projects. Due to this factor the major national project proponents who required high explosives were granted approved to import their consignment of Emulsion explosives by themselves. The present scenario is now different and there are two manufacturers who have been granted approval for the manufacture of Emulsion explosives and presently samples are manufactured.

The main aim of this thesis is to study application of Emulsion explosives and comparative study on the two explosives Water Gel explosives which is being presently used in Srilanka and Emulsion explosives promoted to substitute water gel explosives in future.

As per the instructions of my supervisors, comparative study which included ten blasting tests comprising of 100 bore holes was performed with the participation of the three supervisors, two officials from Geological Survey and Mines Bureau , Mining Engineers from the relevant quarry project and myself. The ten blasting tests were performed in two days where both water gel and emulsion explosives used keeping all parameters such as location, space , burden and quantity same. The results were recorded at two locations by using blast mates provided by Geological Survey and Mines Bureau and Two Technical Officials from the Bureau.

Emulsion explosives are now being locally manufactured by one manufacture with the aim of marketing in future and presently only used at the experimental level by mainly major national projects in the country and the same samples were used for this tests. The Water Gel which is available in the market was used for these tests.

The evaluation of the above practical tests was to clearly indicates that Emulsion explosives when compared with Water Gel explosives in ideal conditions ,exhibits less ground vibration and less air over pressure and this accompanies less environmental hazards in the usage.

CHAPTER 6: RECOMMENDATION AND FUTURE RESEARCH.

6.1 Recommendation

Taking into consideration the evolution performed in the above thesis and the world scenario with the present international usage patterns I strongly recommend that Emulsion explosives is suitable to be used in quarries in Srilanka.

6.2 Future Research

The above tests were limited to one site although done in ideal conditions and in order to get an accurate prediction more tests should be done both in open cast and underground locations and this should be performed in different conditions preferably in different districts with different location

In order to arrive at a definite conclusion a vast amount of blasting tests must be carried both in over cast, underground and deep water blasting. This tests should be performed all over the country in different environments before a definite theory is put published.

7. ANNEXURES

Blasting Test –Phase no 01 (Using Emulsion explosives)

Name of Quarry : Metal Mix Quarry at Meepe,Hanwella Divisional Secretary area.
Date and Time : 2016-07-15 at 11.45 am
Coordinates : 125649 E. 184497 N
Number if holes : 10
Average depth of holes : 3 meters
Average Spacing : 1.6 meters
Average Burden : 1.47 meters
Quantity of explosives per hole:
Emulsion explosives : 125 grams
Ammonium Nitrate : 2.100 kilograms
Electric Detonator :01unit

Figure 7.1: Arrangement of bore holes in phase 1

Figure 7.2: Loading of bore holes in phase 1

Figure 7.3: After the blast in phase 1

Figure 7.4: After the blast in phase 1

Results received from the two Blast mates:

Table 7.1:Results received from Blast mates in phase 1

Blast mate	Coordinates	Ground Vibration	Air over pressure
A	125742 E , 184700 N	0.10 mm/s	104.0 db
B	125581 E , 184579 N	0.18 mm/s	100.0 db

Blasting Test –Phase no 02 (Using Water Gel Explosives)

Name of Quarry : Metal Mix Quarry at Meepe,Hanwella Divisional Secretary area.

Date and Time : 2016-07-15 at 11. 49 am

Coordinates : 125651 E, 184506 N

Number if holes : 10

Average depth of holes : 3 meters

Average Spacing : 1.45 meters

Average Burden : 1.30 meters

Quantity of explosives per hole:

Water Gel explosives : 125 grams

Ammonium Nitrate : 2.100 kilograms

Electric Detonator : 01 unit

Figure 7.5: Arrangement of bore holes in phase 2

Figure 7.6 Arrangement of bore holes in phase 2

Figure 7.7 After the blast in phase 2

Figure 7.8 After the blast in phase 2

Results received from the two Blast mate:

Table 7.2**:**Results received from Blast mates in phase 2

Blast mate	Coordinates	Ground Vibration	Air over pressure
A	125742 E , 184700 N	0.59 mm/s	111.8 db
B	125581 E , 184579 N	2.97 mm/s	110.5 db

Blasting Test –Phase no 03 (Using Emulsion Explosives)

Name of Quarry : Metal Mix Quarry at Meepe,Hanwella Divisional Secretary area.

Date and Time : 2016-07-15 at 11.53 am

Coordinates : 125656 E, 184502 N

Number if holes : 10

Average depth of holes : 3 meters

Average Spacing : 1.50 meters

Average Burden : 1.30 meters

Quantity of explosives per hole:

Emulsion explosives : 125 grams

Ammonium Nitrate : 2.100 kilograms

Electric Detonator : 01 unit

Figure 7.9 Arrangement of bore holes in phase 3

Figure 7.10 Arrangement of bore holes in phase 3

Figure 7.11 After the blast in phase 3

Figure 7.12 After the blast in phase 3

Results received from the two Blast mate:

Table7.3:Results received from Blast mates in phase 3

Blast mate	Coordinates	Ground Vibration	Air over pressure
A	125742 E , 184700 N	0.40 mm/s	116.7 db
B	125581 E , 184579 N	0.22 mm/s	100.0 db

Blasting Test –Phase no 04 (Using Water Gel Explosives)

Name of Quarry : Metal Mix Quarry at Meepe,Hanwella Divisional Secretary area.
Date and Time : 2016-07-15 at 11.56 am
Coordinates : 125635 E, 184482 N
Number if holes : 10
Average depth of holes : 3 meters
Average Spacing : 1.5 meters
Average Burden : 1.4 meters
Quantity of explosives per hole:
Water Gel Explosives : 125 grams
Ammonium Nitrate : 2.25 kilograms
Electric Detonator : 01unit

Figure 7.13: Arrangement of bore holes in phase 4

Figure 7.14: After the blast in phase 4

Results received from the two Blast mate:

Table7.4: Results received from Blast mates in phase 4

Blast mate	Coordinates	Ground Vibration	Air over pressure
A	125742 E , 184700 N	0.085 mm/s	103.5 db
B	125581 E , 184579 N	3.88 mm/s	120.0 db

Blasting Test –Phase no 05 (Using Emulsion Explosives)

Name of Quarry : Metal Mix Quarry at Meepe,Hanwella Divisional Secretary area.
Date and Time : 2016-07-15 at 12.09 pm
Coordinates : 125581 E, 184579 N
Number if holes : 10
Average depth of holes : 3 meters
Average Spacing : 1.7 meters
Average Burden : 1.4 meters
Quantity of explosives per hole:
Emulsion Explosives : 125 grams
Ammonium Nitrate : 2.050 kilograms
Electric Detonator : 01 unit

Figure 7.15: Arrangement of bore holes in phase 5

Figure 7.16: Arrangement of bore holes in phase 5

Figure 7.17: After the blast in phase 5

Figure 7.18: After the blast in phase 5

Results received from the two Blast mate:

Table7.5: Results received from Blast mates in phase 5

Blast mate	coordinates	Ground Vibration	Air over pressure
A	125742 E , 184700 N	0.20 mm/s	110.9db
B	125581 E , 184579 N	0.22 mm/s	100.0 db

Blasting Test –Phase no 06 (Using Water Gel Explosives)

Name of Quarry	: Metal Mix Quarry at Meepe,Hanwella Divisional Secretary area.
Date and Time	: 2016-07-15 at 12.16 pm
Coordinates	: 125742 E, 184700 N
Number if holes	: 10
Average depth of holes	: 3 meters
Average Spacing	: 1.5 meters
Average Burden	: 1.40 meters

Quantity of explosives per hole:

Water Gel Explosives	: 125 grams
Ammonium Nitrate	: 2.050 kilograms
Electric Detonator	: 01 unit

Figure 7.19: Arrangement of bore holes in phase 6

Figure 7.20: After the blast in phase 6

Results received from the two Blast mate:

Table7.6: Results received from Blast mates in phase 6

Blast mate	coordinates	Ground Vibration	Air over pressure
A	125742 E , 184700 N	0.079 mm/s	101.9 db
B	125581 E , 184579 N	1.93 mm/s	107.0 db

Blasting Test –Phase no 07 (Using Emulsion Explosives)

Name of Quarry : Metal Mix Quarry at Meepe,Hanwella Divisional Secretary
Date and Time : 2016-08-05 at 12.02 pm
Coordinates : 125656 E, 184502 N
Number if holes : 10
Average depth of holes : 3 meters
Average Spacing : 1.5 meters
Average Burden : 1.20 meters
Quantity of explosives per hole:
    Emulsion Explosives : 125 grams
    Ammonium Nitrate : 2.100 kilograms
    Electric Detonator : 01 unit

Figure 7.21: Arrangement of bore holes in phase 7

Figure 7.22: Arrangement of bore holes in phase 7

Figure 7.23: Loading of bore holes in phase7

Figure 7.24: After the blast in phase 7

Results received from the two Blast mate:

Table7.7: Results received from Blast mates in phase 7

Blast mate	coordinates	Ground Vibration	Air over pressure
A	125742 E , 184700 N	0.44 mm/s	115.4 db
B	125581 E , 184579 N	0.20mm/s	94.0 db

Blasting Test –Phase no 08 (Using Water Gel Explosives)

Name of Quarry : Metal Mix Quarry at Meepe,Hanwella Divisional Secretary
Date and Time : 2016-08-05 at 12.02 pm
Coordinates : 125651 E, 184506 N
Number if holes : 10
Average depth of holes : 3 meters
Average Spacing : 1.5 meters
Average Burden : 1.20 meters
Quantity of explosives per hole:
Water Gel Explosives : 125 grams
Ammonium Nitrate : 2.100 kilograms
Electric Detonator : 01 unit

Figure 7.25: Arrangement of bore holes in phase 8

Figure 7.26: Arrangement of bore holes in phase 8

Figure 7.27: Loading of bore holes in phase 8

Figure 7.28: After the blast in phase 8

Results received from the two Blast mate:

Table7.8: Results received from Blast mates in phase 8

Blast mate	coordinates	Ground Vibration	Air over pressure
A	125742 E , 184700 N	0.912mm/s	103.5 db
B	125581 E , 184579 N	0.26 mm/s	102.8 db

Blasting Test –Phase no 09 (Using Emulsion Explosives)

Name of Quarry : Metal Mix Quarry at Meepe,Hanwella Divisional Secretary

Date and Time : 2016-08-05 at 12.02 pm

Coordinates : 125645 E, 184483 N

Number if holes : 10

Average depth of holes : 3 meters

Average Spacing : 1.5 meters

Average Burden : 1.20 meters

Quantity of explosives per hole:

Emulsion Explosives : 125 grams

Ammonium Nitrate : 2.100 kilograms

Electric Detonator : 01 unit

Figure 7.29: Arrangement of bore holes in phase 9

Figure 7.30: Arrangement of bore holes in phase 9

Figure 7.31: Loading of bore holes in phase 9

Figure7.32: After the blast in phase 9

Results received from the two Blast mate:

Table7.9: Results received from Blast mates in phase 9

Blast mate	coordinates	Ground Vibration	Air over pressure
A	125742 E , 184700 N	0.87 mm/s	102.8 db
B	125581 E , 184579 N	6.4 9mm/s	119.1 db

Blasting Test –Phase no 10 (Using Water Gel Explosives)

Name of Quarry : Metal Mix Quarry at Meepe,Hanwella Divisional Secretary

Date and Time : 2016-08-05 at 12.02 pm

Coordinates : 125635 E, 184482 N

Number if holes : 10

Average depth of holes : 3 meters

Average Spacing : 1.5 meters

Average Burden : 1.20 meters

Quantity of explosives per hole:

Water gel Explosives : 125 grams

Ammonium Nitrate : 2.100 kilograms

Electric Detonator : 01 unit

Figure 7.33: Arrangement of bore holes in phase 10

Figure 7.34: Checking connection in phase 10

Figure 7.35: Arrangement of bore holes in phase 10

Figure 7.36: After the blast the rocks which fell below in phase 10

Results received from the two Blast mate:

Table 7.10: Results received from Blast mates in phase 10

Blast mate	coordinates	Ground Vibration	Air over pressure
A	125742 E , 184700 N	0.446 mm/s	115.7db
B	125581 E , 184579 N	5.02 mm/s	116.4 db

Preparing and fixing the Blast Mates A and B to monitor readings of test blasts:

Location A

Figure 7.37: Preparing blast mate A for recording

Figure 7.38: Preparing blast mate A for recording

Location B

Figure 7.39: Preparing blast mate B for recording

Figure7.40: Preparing blast mate B for recording

Clearing the Area Prior For Study of Fragmentation:

Figure 7.41: Cleared area which is expected to receive the products of blasts

Figure 7.42: cleared area which is expected to receive the products of blasts

Separating Rock Samples According To Their Sizes

Figure 7.43: Getting prepared to sample rocks

Figure 7.44: Samples of 0-5 centimeters in length

Figure7.45: samples of 10 - 20 centimeters in length

Figure7.46: Samples of 20 cm and above

Table7.11: Specimen format which issued by Ministry of Defence to Assistant Controllers to perform Emulsion testing…

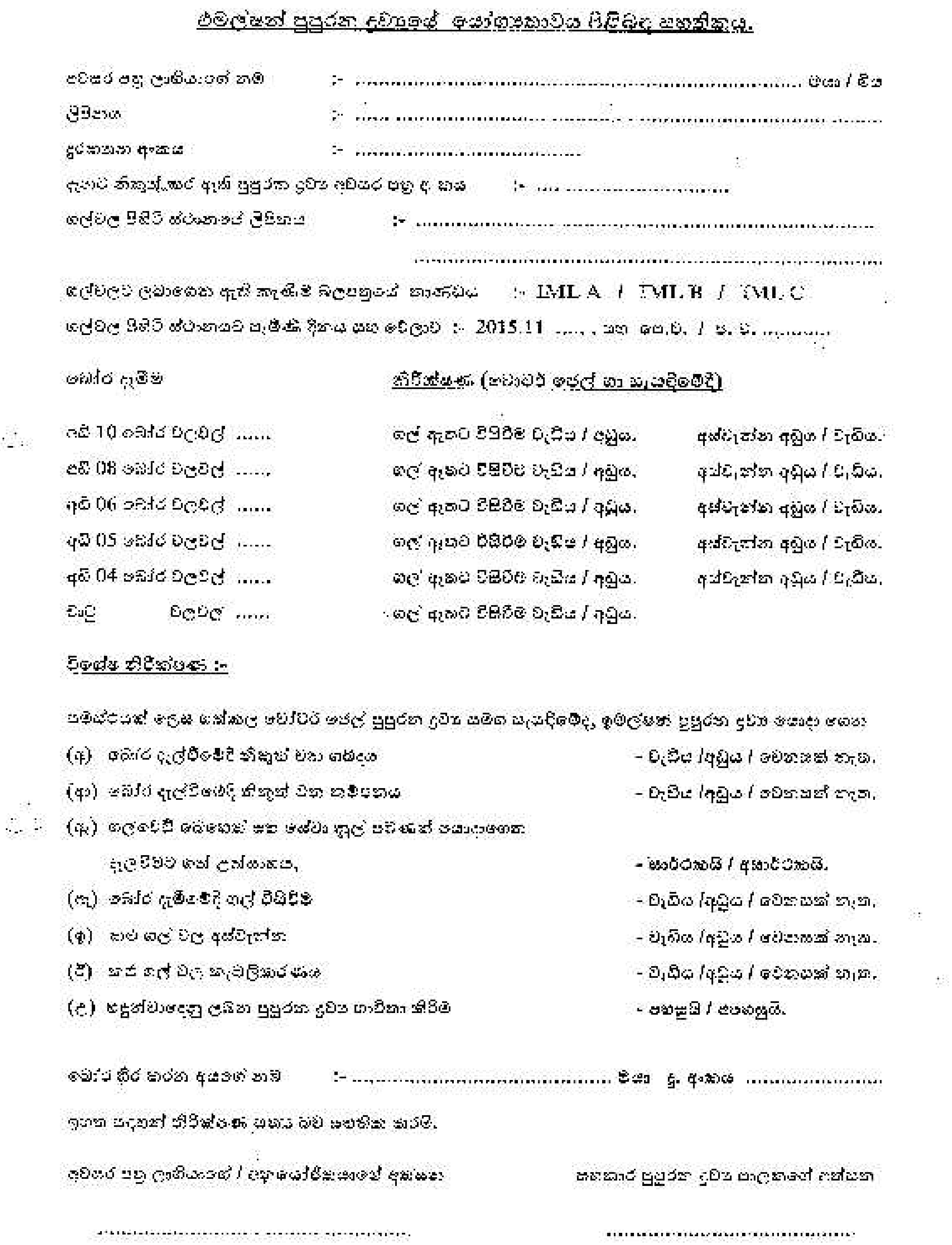

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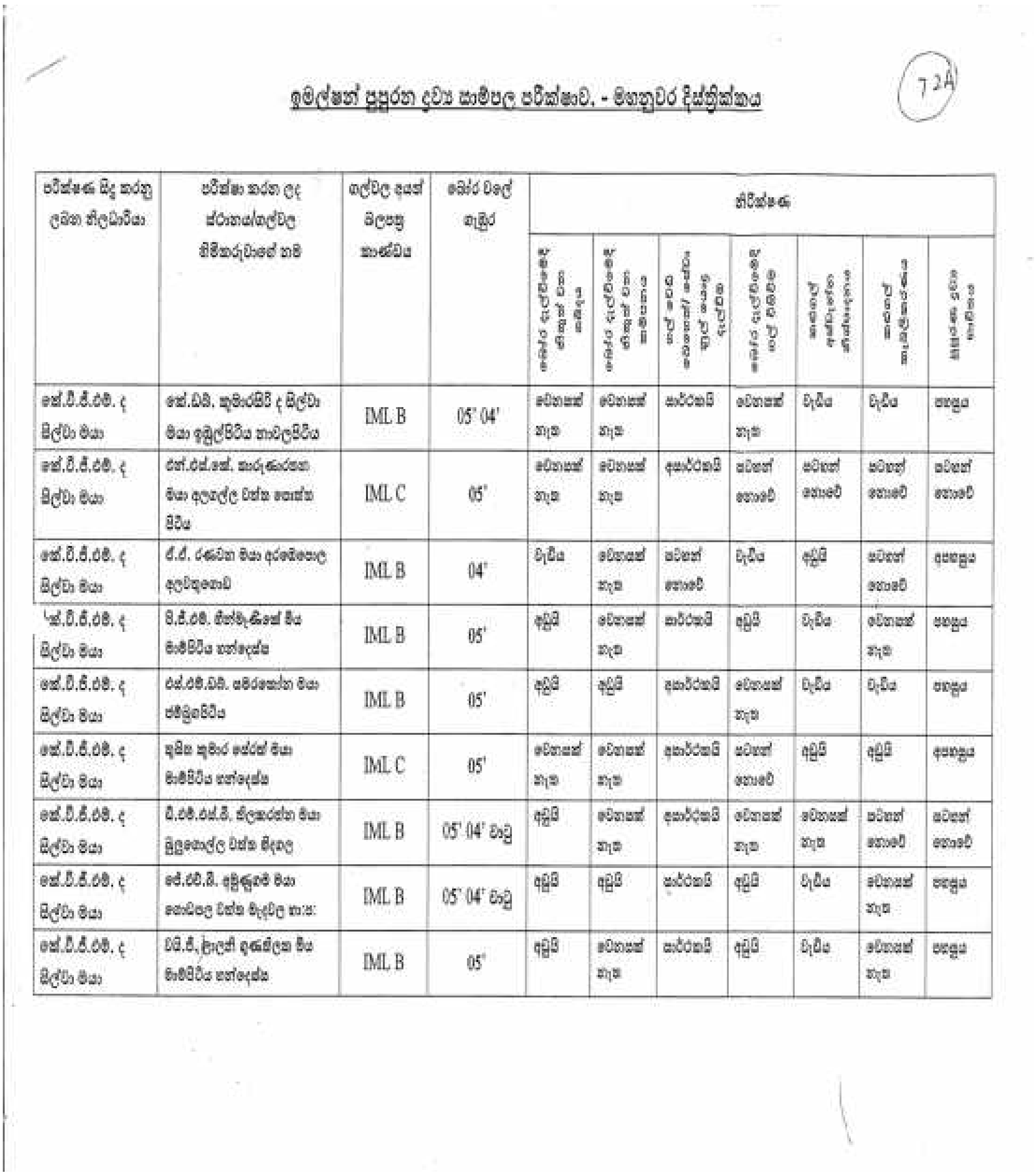
Table 7.12: The completed specimen format of the Emulsion explosives testing prepared by the Assistant Controller of Explosives, Kandy District.



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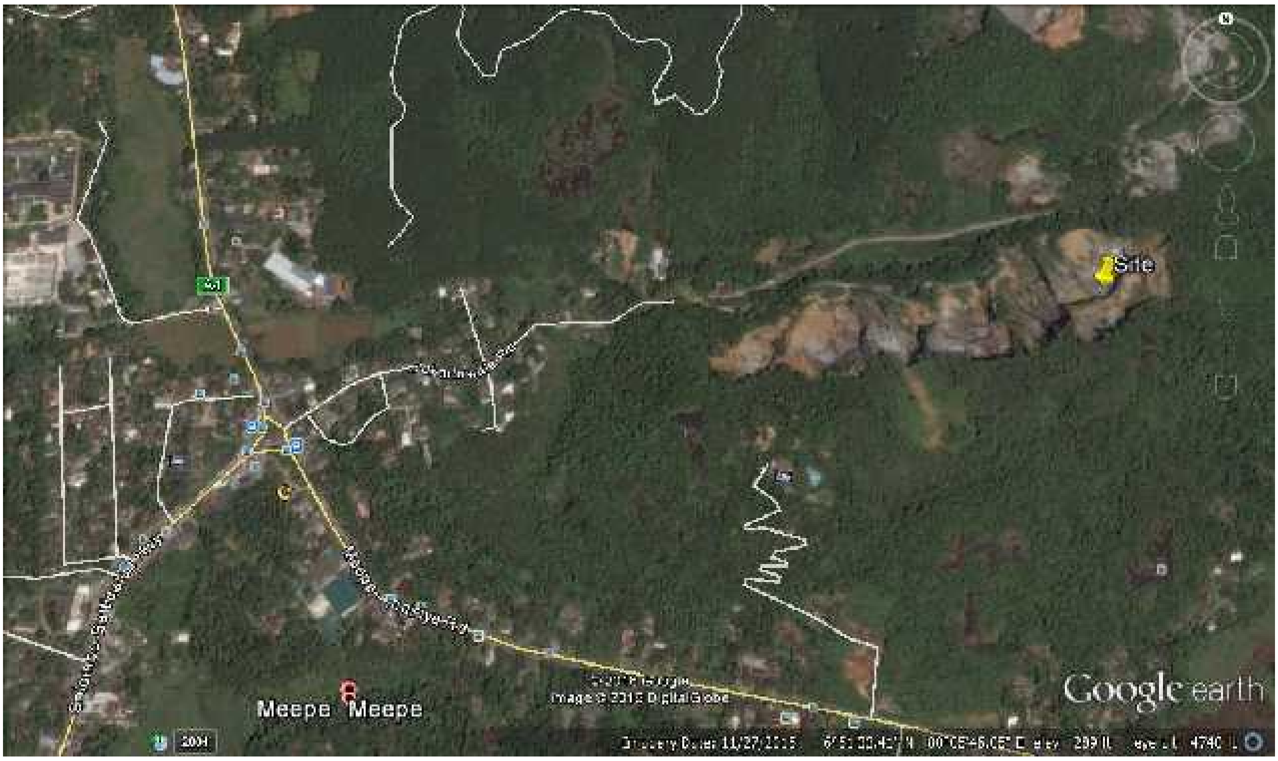
ඉමල්ෂන් පුපුරන ද්‍රව්‍ය සාම්පල පරීක්ෂාව. - මහනුවර දිස්ත්‍රික්කය

පරීක්ෂණ සිදු කරනු ලබන නිලධාරියා	පරීක්ෂා කරන ලද ස්ථානය/ගල්වල හිමිකරුවාගේ නම	ගල්වල අයත් මිලපත්‍ර කාණ්ඩය	බෝර වලේ ගැඹුර	නිරීක්ෂණ						
				බෝර දැල්වීමේදී නිකුත් වන ශබ්දය	බෝර දැල්වීමේදී නිකුත් වන කම්පනය	ගල් කඩන [illegible] දැල්වීම	බෝර දැල්වීමේදී ගල් විසිවීම	කඩගල් අපේක්ෂිත නිශ්පාදනය	කඩගල් කැබලිකරණය	සිදුරක ද්‍රව්‍ය පිරවීම
ජේ.ඩී.සී.එම්. ද සිල්වා මයා	ජේ.ඩබ්. කුමාරසිරි ද සිල්වා මයා ඉඹුල්පිටිය තාවලපිටිය	IML B	05' 04'	වෙනසක් නැත	වෙනසක් නැත	සාර්ථකයි	වෙනසක් නැත	වැඩිය	වැඩිය	පහසුය
ජේ.ඩී.සී.එම්. ද සිල්වා මයා	එන්.එස්.කේ. කරුණාරත්න මයා අලවල්ල වත්ත පොත්ත පිටිය	IML C	05'	වෙනසක් නැත	වෙනසක් නැත	අසාර්ථකයි	සටහන් නොවේ	සටහන් නොවේ	සටහන් නොවේ	සටහන් නොවේ
ජේ.ඩී.සී.එම්. ද සිල්වා මයා	ඒ.ඒ. රණවන මයා අරමිපොල අලවතුගොඩ	IML B	04'	වැඩිය	වෙනසක් නැත	සටහන් නොවේ	වැඩිය	අඩුයි	සටහන් නොවේ	අපහසුය
ජේ.ඩී.සී.එම්. ද සිල්වා මයා	පී.ජී.එම්. [illegible] මිය මාවිපිටිය හන්දෙස්ස	IML B	05'	අඩුයි	වෙනසක් නැත	සාර්ථකයි	අඩුයි	වැඩිය	වෙනසක් නැත	පහසුය
ජේ.ඩී.සී.එම්. ද සිල්වා මයා	එස්.එම්.ඩබ්. සමරකෝන් මයා ජම්බුගහපිටිය	IML B	05'	අඩුයි	අඩුයි	අසාර්ථකයි	වෙනසක් නැත	වැඩිය	වැඩිය	පහසුය
ජේ.ඩී.සී.එම්. ද සිල්වා මයා	කුසීන කුමාර පෙරේරා මයා මාවිපිටිය හන්දෙස්ස	IML C	05'	වෙනසක් නැත	වෙනසක් නැත	අසාර්ථකයි	සටහන් නොවේ	අඩුයි	අඩුයි	අපහසුය
ජේ.ඩී.සී.එම්. ද සිල්වා මයා	පී.එම්.එස්.බී. තිලකරත්න මයා මුලුගොල්ල වත්ත මිදලා	IML B	05' 04' වාවු	අඩුයි	වෙනසක් නැත	අසාර්ථකයි	වෙනසක් නැත	වෙනසක් නැත	සටහන් නොවේ	සටහන් නොවේ
ජේ.ඩී.සී.එම්. ද සිල්වා මයා	ජේ.එම්.බී. අමුණුගම මයා ගොඩපොල වත්ත මැදවල නා:	IML B	05' 04' වාවු	අඩුයි	අඩුයි	සාර්ථකයි	අඩුයි	වැඩිය	වෙනසක් නැත	පහසුය
ජේ.ඩී.සී.එම්. ද සිල්වා මයා	ඩබ්.ජී. ප්‍රියන්ති ගුණතිලක මිය මාවිපිටිය හන්දෙස්ස	IML B	05'	අඩුයි	වෙනසක් නැත	සාර්ථකයි	අඩුයි	වැඩිය	වෙනසක් නැත	පහසුය

Figure 7.47 Location and site maps

Site map

Location map



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