CHAPTER - 01

1. INTRODUCTION

1.1. Introduction to research

Blasting is the predominant method of rock breaking in the mining industry. Other associated disciplines namely thermodynamics, shock wave propagation, explosive chemistry, and physics of rock mechanics highly contribute to the subject of rock blasting. Controllable factors such as blasting design parameters and uncontrollable parameters such as physical and geotechnical properties of rocks, and some geological conditions affect the breakage and fragmentation of rocks. Vast amount of research conducted in the past, no definite blasting theory has been developed that fully explain the mechanisms of rock breakage. Because hardness is different from rock to rock and blasting is different from site to site and also rock type nature is variable in place to place. This research is going to be conduct with the blasting parameters kept constant and with the only variable factor being the type of rock. Six locations have been selected for the study with different rock types having enough solid blasting space for six blasts in each. Blasting data is collected for further analysis.

1.2. Problem statement

Mining involves the activities of drilling, blasting, loading, haulage, crushing and grinding of rock where drilling and blasting costs constitute up to 30% of the total operational cost of mining. In the event of oversize formation and resultant necessity for secondary blasting, the costs may go up further up to nearly to 50%. The efficiency of the mining process can be improved with cost reductions using the correct explosive amount to obtain optimum fragmentation, a problem faced by any mining engineer in planning blasting operations.

It is equally important to identify the correct combination of parameters with a view to improving the fragmentation levels of poorly fragmented rocks. Establishing a relationship between the performance of emulsion and the degree of fragmentation of hard rock, conducting field tests will be essential for future investigations. The research will lead to determine some of the strength properties affecting with emulsion explosives in field. The inter relationships are focused to the development of relevant empirical relationship between the explosive quantities and the rock properties. To evaluate the interaction between explosive usage and the rock types for better productivity rate is to be effective for mining industry. The productivity rate is influenced by the degree of fragmentation.

1.3. Aims and objectives

This research is aimed at examining the efficiency of emulsion explosives in breaking different rock formations encountered in quarrying practices in Sri Lanka with evaluating the performance of emulsion explosives on rocks at different geographical locations with the degree of fragmentation, blasted rock volume, usage of explosives and specific charge being the ultimate performance indicators. Quarries with different rock types have been selected for performance analysis in blasting tests. All the selected blasting parameters have been kept constant throughout the study and changing only the rock types. Identification of suitable metal quarries with varying rock properties are very important for the study.

1.3.1. Study aims at evaluating

1. Explosives in different rock types with blasted rock volumes.
2. Minimizing the specific charge (Powder factor).
3. The uniformity of fragmentation.
4. Optimizing the blasting cost.

1.4. Limitations

1. Locating of quarries with similar geological characteristics in different geographical settings where tastings are to be carried out.
2. Blasting has to be carried out within the regulatory limits imposed by the Geological Survey and Mines Bureau (GSMB), the Central Environmental Authority (CEA) and other government regulatory agencies.
3. Social problems.

CHAPTER - 02

2. LITERATURE SURVEY

2.1. History of rock blasting

The first method of rock breaking was reported to be by fire setting adopted in the second century B.C. As for explosives, black powder has been first used for blasting in Hungary in 1627. It gave way to dynamite in the mid 1800s when Sir Alfred Nobel of Sweden saturated porous earth with nitroglycerin. In later years, sugar cane and wood pulp replaced earth in his formula. [Source - The History of Rock Drilling. Author -P.L.McCarty].

Although the Egyptians built pyramids by using hard rock in 6000 years ago. In the early Sri Lankan history, at the time of Anuradhapura era huge amount of massive stones were used to build Dagebas, storied buildings, tanks and various monuments. These tasks involving stone separation, cutting, transportation, handling and perfect designing are very wonderful.

The concept of drilling for rock blasting was proposed by Martin Weigel, a mine superintendent at Freiberg, Germany, in 1613 with the successful use of the said method attributed to Casper Windt, at Schemintz, four years later. But it was two centuries later practical mechanized rock drilling was demonstrated. The use of black powder for blasting, remains a high risk in the absence of a reliable fuse. Much of the danger of premature explosion, hang fire and misfire was overcome with the invention of safety fuse by William Bickford of Tucking Mill in the UK in 1831. Electric detonator had been invented by Moses Shaw in New-York, while nitroglycerin was discovered by Sobrero in 1847. [Source - The History of Rock Drilling. Author -P.L.McCarty].

In 1844 Brunton, and Englishman, suggested using compressed air in rock drill, naming the "Wind Hammer". It was five years later when J.W.Fowle, in Boston, took a patent for the modern rock drill with many additional features. With further enhancement of the Fowle drill by Bartlett in 1855 tested it in the first major tunneling project, the Mount-Genis tunnel. The steam driven drills were modified by Sommeiller in 1860s to make a reliable machine. [Source - The History of Rock Drilling. Author -P.L.McCarty]

2.1.1. Explosives history

With Alfred Nobel's early efforts in 1863 and 1864 reliably making nitroglycerin and nitroglycerin mixed black powder for blasting in drill holes emerged a clear understanding as to the importance of the shock (concussion) generated by his "detonator" in producing the "especially violent explosions" allowed nitroglycerin to be used for practical rock blasting. F.A. Abel (1869) demonstrated that unconfined charges of guncotton, nitroglycerin, dynamite and mercury fulminate burned if ignited by a flame but "detonated" if exposed to the blow of a Nobel Detonator. The real physical nature of the phenomenon of detonation was clearly recognized as a propagating explosive wave by Berthelot and Vieille and Mallard and Le Chatelier in parallel investigations of gaseous explosions conducted in 1881. In 1893, Shuster suggested an analogy between detonation waves and the nonreactive shock waves which had been discussed by Riemann and others in 1860. Shuster pointed out that the detonation wave is headed by a shock front which advance with constant velocity into the unreacted explosive and is followed by a zone of chemical reaction which supports the detonation wave. This suggestion that of the detonation wave as a reactive shock laid the groundwork for Chapman (1899) and Jouguet (1905) to develop the classical Chapman-Jouguet (CJ) hydrodynamic theory of steady-state detonation.

The Chapman-Jouguet theory is described by a one-dimensional model in which the chemical energy is instantaneously released in the discontinuous shock front across which the conservation laws apply. The detonation velocity was assumed to be the minimum velocity given by the conservation laws. During world war II, the CJ theory was refined independently by the Russian Zeldovich (1940), American scientist Von Neuman (1942), and the German scientist Doring (1943). They assumed that chemical energy release did not take place in the shock front, but at a finite zone behind the front of the detonation wave. [Source - Rock Blasting and Explosives Engineering by Prof. Per-Anders Persson, Roger Holmberg and Jaimin Lee].

The invention history of emulsion explosives and blasting agents began with the invention by Egly and Neckar (1964) in the USA that a relatively water resistant blasting agent, albeit with relatively limited lifetime could be produced by mixing crystalline ammonium nitrate (AN) with a water in oil emulsion made by high shear mixing of a water solution of AN into a mix of oil and emulsifier. Gehrig (1965) produced an all-solution emulsion explosives by high-shear mixing a solution of nitric acid, sodium nitrate and water into a fuel phase consisting of mineral oil plus an emulsifier such as Sorbitan Monooleate (Span 80). The resulting explosives called 'Aquanite' had limited stability and was chemically reactive with some Ores because of its acid content. [Source - Rock Blasting and Explosives Engineering by Prof. Per-Anders Persson, Roger Holmberg and Jaimin Lee].

The first stable, practically useful emulsion blasting agents were invented by Bluhm (1969). He emulsified a hot water solution ammonium nitrate (AN) and Sodium Nitrate in a fuel phase consisting of a mineral oil and emulsifier and made the emulsion detonable in charge diameters down to 75mm by introducing gas bubbles by aerating in a high shear rate mixer, by chemical gassing or by adding hollow glass micro balloons. The product which was not cap sensitive and was called 'Aquaram' or with adding aluminum 'Aquanal'.

Wade (1973a, 1973b, 1978) finally made cap-sensitive Ammonium Nitrate emulsion explosives by initially using a combination of carefully optimized air inclusions such as glass micro balloons plus the catalytic action of heavy metal ions such as Cupper, Chromium and ultimately showed that all-AN cap - sensitive emulsion without catalysts could be produced by carefully balancing the water and micro balloons content.

Clay (1978) was the first to prepare a blasting agent by mixing ammonium nitrate-fuel oil (ANFO) and/or crystalline ammonium nitrate into an emulsion matrix containing no air bubbles or other sensitizing agent. This invention has led to the development of a whole range of very cost effective blasting agents consisting of blends of prilled ANFO with various weight percentages of emulsions. [(Source - Rock Blasting and Explosives Engineering by Prof. Per-Anders Persson, Roger Holmberg and Jaimin Lee. P-85,86).(Rock Blasting and Explosives Engineering by Per-Anders Persson, Professor of mining engineering, Director research Center for Energetic Materials, New Mexico Institute of mining and Technology, Socorro, New Mexico, USA. Roger Holmberg, Vice president and Technical Director, Nitro Nobel AB, Gyttorp, Sweden. Jaimin Lee, Senior Research Scientist, Agency for Defense Development, Taejon, Korea)].

2.1.2. Blasting process

Breakage and displacement of material occur during and after complete the detonation of a confined charge.

The sequential time frames are defined as follows,

1. Detonation
2. Shock or Stress wave propagation
3. Gas pressure expansion
4. Mass movement

One event phase can occur simultaneously with another at specific time intervals.

2.1.2.1. Detonation.

The term **“Detonation”** indicates that the reaction is moving through the explosive faster than the local speed of sound in the unreacted explosive, creating a shock wave. The ingredients of an explosive consisting of a fuel and oxidizer combination, upon detonation, are immediately converted to high pressure and high temperature gases. Detonation pressure is generally expressed as a function of the velocity of detonation and density of the explosives as,

$P_d = (2.325 \times 10^{-7}) \times \rho \times VOD^2$..(01)

where :

P_d = Detonation Pressure (kilo bars)

ρ = density (grams per cubic centimeter)

VOD = Velocity of detonation (feet per second)

[Source - Explosives and Rock Blasting, Field Technical Operations.Atlas Power company, The USA. (P-159-164)]

Generally, explosives yielding higher detonation pressure are required to fracture materials that are massive, fine grained, hard, tightly bonded, and strongly consolidated with heavy burdens. The detonation waves start at the point of primer initiation in the explosive column and travels along the explosive column through bore hole, that most probably cylindrical propagation. Borehole coupling is critical to good fragmentation of rock. The diameter of the borehole will affect the blasting consideration concerning fragmentation, air blast, fly rock and ground vibration. [Source-Explosives and Rock Blasting, Field Technical Operations. Atlas Power company, The USA.].

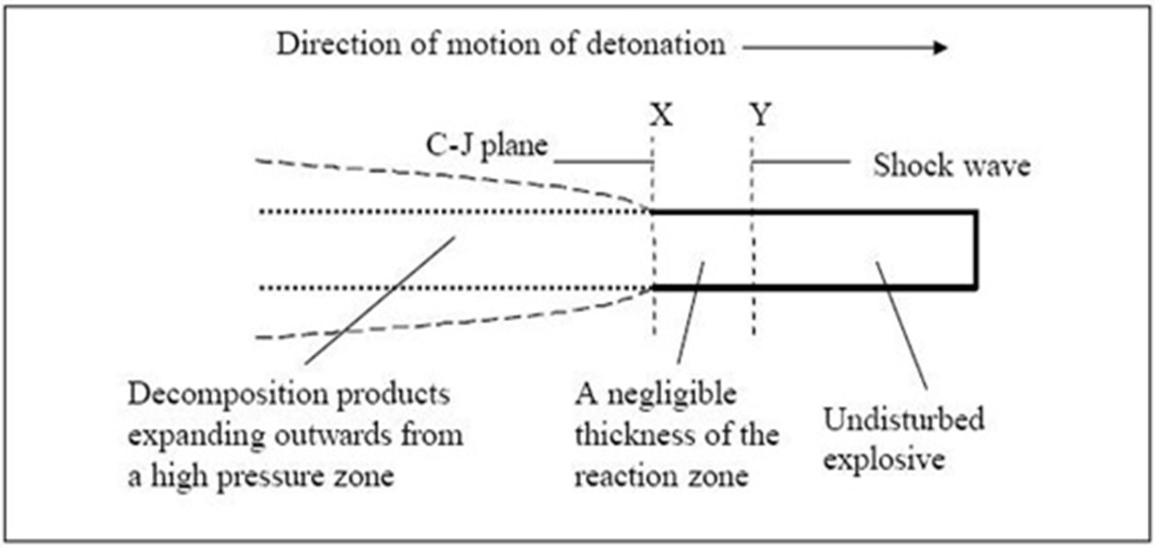

Figure-1 . Sketch of detonation head. [Source– Internet:-Rock breakage and blast design considerations in open pit, by Dr. ParthaDasSharma.]

The explosive material directly in front of the detonation head is totally unaffected until the detonation head passes through it. The sketch of detonation head is shown in *Figure-1*.

[Source - Internet - https://miningandblasting. wordpress.com/2012/10/12/rock-reakage-and-blast-design-considerations-in-openpit, by Partha Das Sharma].

The complete detonation and energy release within the entire column would occur shorter than 3ms. The greater the difference in detonation velocities and the harder the material to be blasted, the more pronounced are the results.

2.1.2.2. Shock and stress wave propagation.

Immediately following the detonation, is the shock and stress wave propagation throughout the rock mass. This highly pressured waves transmitted through the rock mass results, in part, from the rapidly expanding high pressure gas impacting the borehole wall. The geometry of dispersion depend on many factors, such as explosive characteristics, the location of the initiation point, shock wave velocity in the rock etc. The pressure next to the borehole wall will rise quite quickly to its peak and then rapidly decay exponentially. The quick decay is due to cavity expansion of the bore hole and increased gas cooling. Cavity expansion around the borehole can occur through crushing, pulverization, and/or displacement of material and can range anywhere from about 1 to 3 hole diameters, depending on the medium and explosive used. Generally, extensive compressive, shear, and tensile failure occurs as a region of pulverized material since the wave energy is at its maximum near the borehole wall. [Source- Explosives and Rock Blasting, Field Technical Operations.Atlas Power company, The USA. (P - 164-167)].

As the stress wave front proceeds outward, it has a tendency to compress the material at the wave front through a volume change. At right angle to this compressive front, there exists another component referred to as the tangential stress. The tangential stress, if large enough, can cause tensile failures at right angles to the direction of propagation. The largest tensile failures are expected to occur close to the borehole where the tangential stress is high enough for failure to occur. Both the compressive and tensile components of the wave front decay with distance from the borehole. See *Figure - 2*.

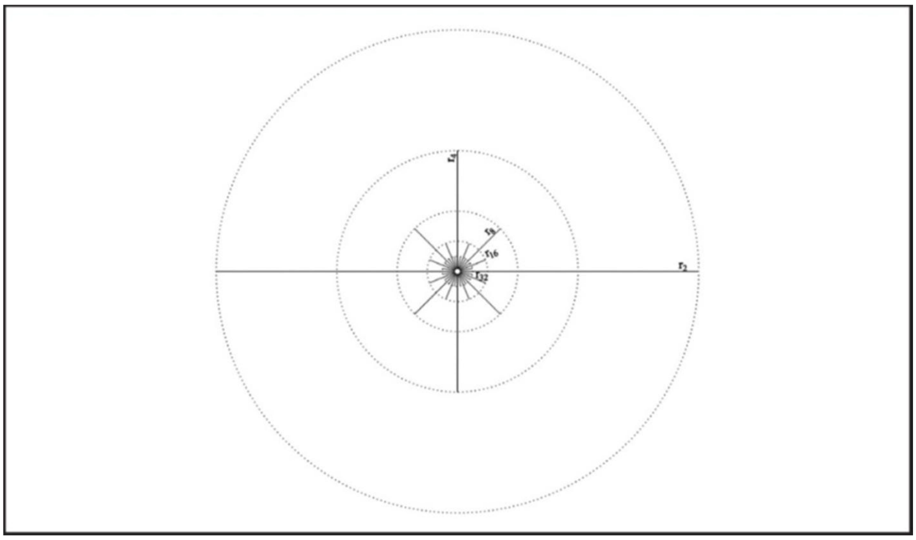

Figure - 2. Schematic illustration of tension crack length and density around single shot blast hole. [Source - Internet - TORBICA,S.,LAPCEVIC,V.Rock breakage by explosives. European International Journal of Science and Technology, p. 96-104, 2014.]

For the most part, the partitioning of energy depends on the ratio of the acoustic impedance of the materials on either side of the influence. Acoustic impedance, Z, for any material is defined as,

$Z = \rho \times V_p$ .... (02)

Where:

Z = acoustic impedance ($Pa.sm^{-3}$)

ρ = density of material(kgm^{-3})

V_p= sonic velocity of material ($m\ s^{-1}$)

[Source-Explosives and Rock Blasting, Field Technical Operations.Atlas Power company,The USA. (P - 164-167)].

2.1.2.3. Gas pressure

During and/or after stress wave propagation, the high pressure, high temperature gases impart a stress field around the blast hole that can expand the original borehole, extend radial cracks, and jet into any discontinuity. It is the gases that have jetted into discontinuities and the fracture network that is either fully developed or being developed, along with the impulse imparted to the material by the detonation, that are responsible for the displacement of broken materials.

The gases produced will first migrate into existing cracks, joints, faults, and discontinuities, in addition to seams of materials that exhibit low cohesion or bonding at interfaces. If a discontinuity of seam between the borehole and free face is sufficiently large, the high pressure gases will immediately vent to the atmosphere, rapidly reducing the total confinement pressures, which will result in reduced displacement of broken and fragment material. The confinement times of gas pressures within a rock mass very significantly depending on the amount and type of explosive, material type, and structure, fracture network, amount and type of stemming, and burden. [Source-Explosives and Rock Blasting, Field Technical Operations.Atlas Power company, The USA. (P - 167-168)].

2.1.2.4. Mass movement

Mass movement of material is the last stage in the breaking process. The majority of fragmentation has already been completed through compressional and tensile stress waves, gas pressurization, or a combination of both. It should be emphasized that in a typical shot hole blast, one event phase can occur simultaneously with another at specific time intervals. [Source-Explosives and Rock Blasting, Field Technical Operations.Atlas Power company, The USA. (P - 168-169)].

2.2. Emulsion usage

In Sri Lankan mining and quarrying industry locally manufactured water gel has been widely used explosive for rock blasting purpose since 2011. The large scale national projects have been used imported emulsion explosive for their excavation purpose. The locally manufactured emulsion explosives are introducing to the quarry industry since this year (2016). Sri Lankan annual Water gel explosives or Emulsion explosive requirement is about eight hundred metric tons per year.

The nitroglycerine based commercial explosive usage was successfully changed to water gel explosive in Sri Lankan quarry industry since 2014. Now it is time to enter to the much safer emulsion explosives usage for Sri Lankan quarry industry and the significant feature of the emulsion explosive is higher VOD compared to the water gel explosives.

2.2.1. What is Emulsion explosives

In commercial explosives, the ingredients' particle size is an important factor which determines the rate at which the ingredients react with each other. This is due to differences in detonation velocities, to differences in the ratio between shock wave and heave energy, and to differences in the expansion work done before the rock breaks and the gaseous products are ventilated through the formed creaks. The solid oxidizer, Ammonium Nitrate (AN) grains, called prills, in Ammonium nitrate and

Fuel Oil mixture (ANFO) have a diameter around 2mm and are impregnated with the liquid fuel oil. [Source -Comprehensive Technical Report for Emulsion explosives By Eng. Saurabh Roy, India].

The Emulsion oxidizer is a liquid salt solution made up of 0.005 mm droplets, with each droplet surrounded by a thin oil film. It is easy to understand that the specific contact surface between oxidizer and fuel is many orders of magnitude larger for the emulsion explosives than for the Ammonium Nitrate and Fuel Oil mixture (ANFO). [Source-Comprehensive Technical Report for Emulsion explosives By Eng. Saurabh Roy, India].

These large differences in reaction surface area will obviously influence the reaction rate for the two explosives, and at least partially compensate for the presence of a considerable percentage of water in the emulsion. *Figure-3 and 4*. The size of a typical single explosive molecule is six orders of magnitude smaller than AN prills grain and four orders of magnitude smaller than an emulsion droplet.

Emulsions share most of the properties of slurries. The main difference is the mixture of the explosive components. Emulsions are prepared in the form of water-in-oil emulsion phase. The internal phase is composed of a solution of oxidizer salts suspended as microscopically fine droplets, which are surrounded by a continuous fuel phase. Emulsion thus formed is stabilized against liquid separation by an emulsifying agent. As the components of emulsion explosives are microscopic in size and the oxidizer and fuels are so intimately mixed, emulsions have very high velocity of detonation (VOD) and the resulting chemical reaction and detonation release essentially all of the stored energy.

Emulsion is a highly efficient explosive, due primarily to it microscopic particle size. In contrast, explosives with varying particle size such as ANFO or water gels will not have uniform burning rate, and therefore, will not be efficient as emulsion.

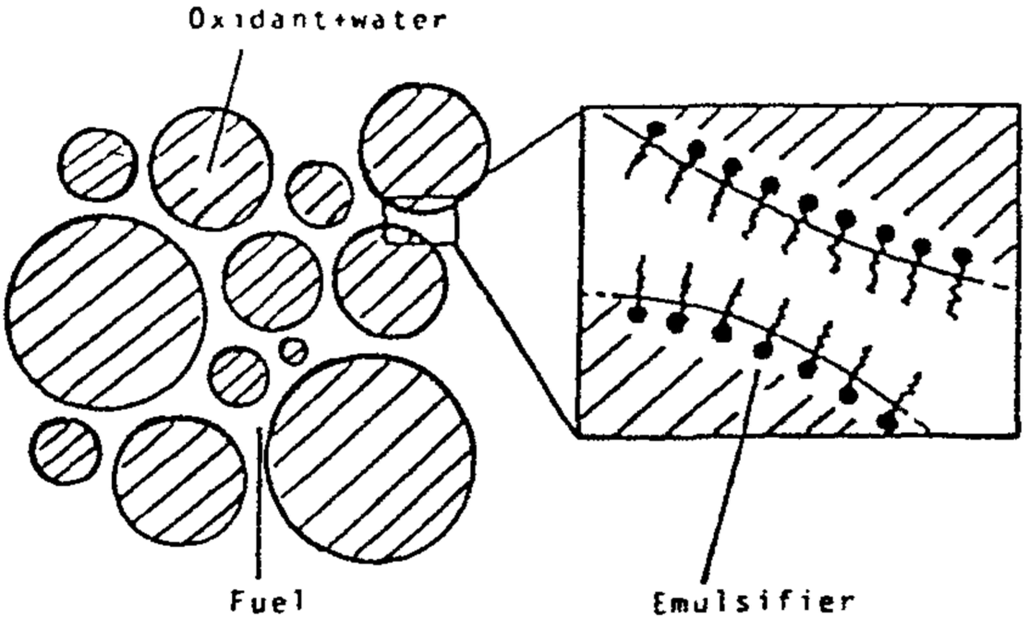

Figure-3: Water in the oil disperse emulsifier
(Source - Internet – Ström,Tore et al - Ström&Gulliksson AB

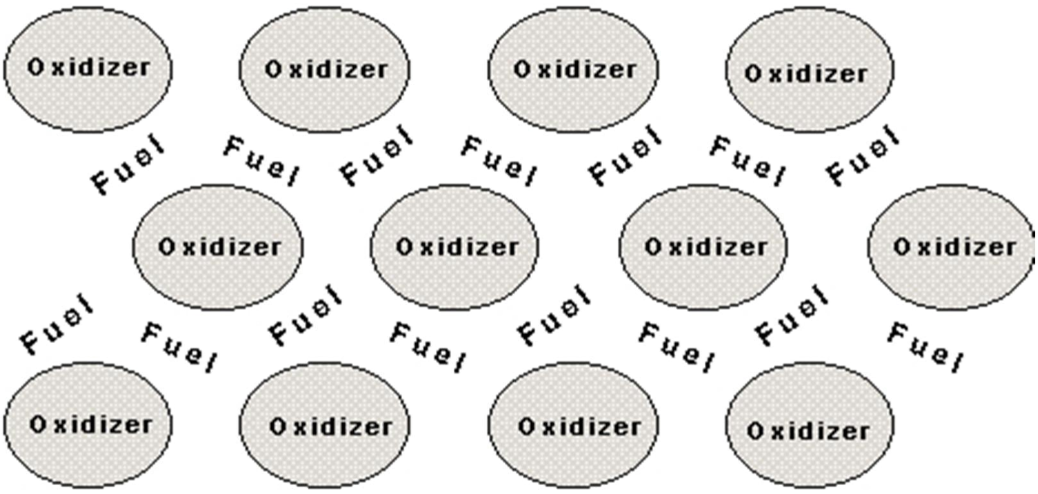

Figure-4: Schematic of Water-in-oil emulsion.
[Source- Internet: http://masters.donntu.org/2012/feht/ilina/library/article10.htm].

2.2.2. Properties of emulsion

Density	-	0.8 - 1.3 g/cm^3
Velocity of Detonation(VOD)	-	4300 - 5500 m/s
Detonation pressure	-	6600-7700 kPa
Bore hole pressure	-	3300-3850 kPa
Bulk strength	-	1.20-1.27
Weight Strength	-	0.82-0.88
Water resistance	-	Excellent
Sensitivity	-	Cap Sensitive

Some of above properties depend on the bore hole diameter. Blasting with same explosives using drill holes with different hole diameters in rock quarries have shown variable production. Safety of emulsions are very high because separate constituents are not characterized as explosives compared with other explosive such as dynamite.

It is well known in rock blasting, that explosives with a high brisance (or a high shock energy), and high detonation velocity explosives are well suited for blasting in hard competent rock. A low brisance explosive such as ANFO (which produce lower shock wave energy but a relatively high bubble expansion or heave energy) is better suited for soft, porous or heavily fractured rock. The best matching for optimum shock wave transmission to the rock occurs when the detonation impedance equals to the impedance of the rock materials. [Source: Rock Blasting and Explosives Engineering by Prof. Per-Anders Persson, Roger Holmberg and Jaimin Lee.P-100].

Many commercial explosives have a reaction zone which extends 10 mm or more behind the front. The effect of confinement is to slow down the decrease of pressure and temperature behind the detonation front, thereby increasing the reaction rates. Increased confinement thus has a similar effect to increased charge diameter. Without confinement, which is nearly the case for a small diameter, decreased charge diameter and also incomplete detonation zone and reaction front built. Whereas the same explosive may detonate properly when complete filling the bore hole. [Source - Toward Detonation Theory by Anatoly N. Dremin, Institute for Chemical Physics Research, Russian Academy of Science, 142342, Chernogolovka, Russia. P-11,15].

When the explosive detonation initiates the rock starts to break, cracks open up and detonation products propagate and expand through surroundings. These events which depend on the rock properties will happen long before the lower pressure region has been reached. Typically this happens for a very high pressure and detonating products have expanded to 10 – 20 times the initial volume. At this stage detonation energy corresponds to the expansion work used for breaking the rock. [Source - Internet -Rock breakage and blast design considerations in open pit, by Dr.ParthaDasSharma.]

2.3. Sri Lankan Rocks types

Rock is defined as "Aggregate of minerals of one or more kinds in varying proportions".(A bounded aggregate of minerals, mineraloids, or fragments of other rocks)**.** [Source -Dictionary of Physical Geography -By -SzabolcsÁkosFábián - University of Pécs, ZoltánKarancsi - University of Szeged, JánosKovács - PTE TTK FI, DénesLóczy - PTE TTK KTI, GáborVarga - PTE TTK FI , 2010].

In Sri Lanka 90% of the area is covered by Precambrian (over 600 million years old) metamorphic rocks. The other 10% which is in the Northern part of Sri Lanka consist of Miocene age (0-25 million years) lime stone. Sri Lankan rocks are high grade metamorphic rocks belonging to amphibolites and granolite facing metamorphism. [Source -Internet -http://www.slideshare.net/indirankaralasingham/gelogy-mineral-resource-of-srilanka].

In classification of such rocks the mineralogical components, texture and structure are used. Using fresh rock samples collected from exposed rocks and boreholes are used to identify engineering properties. The rocks are made of grains. They are coarse grained, medium grained and fine grained. Grain size in rock can mean the size of crystal granules. The individual grain sizes are different, some grain can be seen without magnifiers but most of the rocks is made of smaller size grains. See table-1 for details.

Foliation and Granular are the two distinctive metamorphic textures that can be identified in the field. Foliation represents a distinct plane of weakness in the rock. Foliation is caused by the re-alignment of minerals when they are subjected to high pressure and temperature. Individual minerals align themselves perpendicular to the stress field such that their long axes are in the direction of these planes. Usually a series of foliation planes can be seen parallel to each other in the rock. Well developed foliation is characteristics of most metamorphic rocks. Metamorphic rocks often break easily along foliation planes. (Source - Internet)

A granular texture is developed if a rock's chemical composition is close to that of a particular mineral. This mineral will crystallize if a rock is subjected to high pressure and temperature. A granular texture is characteristic of some metamorphic rocks. (Source - Internet)

As the grade of metamorphism increase (more temperature and pressure) both crystal size and the coarseness of foliation increases. Therefore gneiss represents more intense metamorphism (or a higher grade) than does schist. Some fine grained metamorphic rocks like schist have larger crystals present. These crystals are called porphyroblasts. Porphyroblasts represent minerals that crystallize at a faster rate than the matrix minerals. Garnet is a common porphyroblasts mineral. (Source - Internet)

Table-1: Metamorphic rocks by texture (Source - Internet).

	Grain Size		
	Fine (< 0.1 mm diameter)	Medium (0.1-2 mm diameter)	Coarse (> 2 mm diameter)
Poorly foliated	Hornfels	Marble, Quartzite	Marble, Quartzite
Well Foliated	Slate	Schist	Gneiss
Well Foliated and Sheared	Mylonite	Mylonite, Schist	Augengneiss

CHAPTER - 03

3. RESEARCH METHODOLOGY

Identification of suitable metal quarries with different rock types island wide for the study. The assessment of the rock-mass, structural fractures, discontinuities, sets of discontinuities or cracks, which may affect the response to blasting operations and results. Basic information of rock-mass characteristics is very important for the field application. The rock-mass selection for this project is critical, because of the features of rock-mass directly influence the results.

1. Selection of blasting parameters for research study to identified different rock types.

2. Blast to be planned keeping blasting parameters constant. Namely, Hole diameter, Explosives charge, Burden, Spacing and Stemming. Only the difference is rock type.

3. Based on the above result, identify the rock types resulting in optimizing the fragmentation levels of such quarries. (Blasted rock volumes and Degree of fragmentation).

As a result, the efficient use of explosives, along with the proper selection, will be the keys to a successful blasting program. After comparison of the results of fragmentation that some empirical rules showing to how explosives behave with the different rock types with different hardness will be formulated.

In field application, using constant weight of emulsion and constant weight of ANFO explosives will be used for the same borehole diameter and depth for selected different rock types and the following measurements will be taken in the field study. See table-2.

Table-2: Field application measurements and results are tabulated format .

Number of Borehole	**01**	**02**	**03**	**04**	**05**	**06**
Borehole diameter (mm)	38	38	38	38	38	38
Borehole depth (m)	1.524	1.524	1.524	1.524	1.524	1.524
Burden (m)	0.914	0.914	0.914	0.914	0.914	0.914
Emulsion (kg)	0.13	0.13	0.13	0.13	0.13	0.13
Detonator (No.)	01	01	01	01	01	01
AN/FO (kg)	0.35	0.35	0.35	0.35	0.35	0.35
Stemming (m)	0.6096	0.6096	0.6096	0.6096	0.6096	0.6096
Explosive Column height (m)	0.914	0.914	0.914	0.914	0.914	0.914
Fly rock thrown distance (m)	?	?	?	?	?	?
Fragment scattered area (m^2)	?	?	?	?	?	?
Material quantity after blasting. (volume) Cubes	?	?	?	?	?	?
Specific Charge (kg m^{-3})	?	?	?	?	?	?

Fragmentation analysis will be carried with clear photographs comparing with the measurements known object as scale at every blast in six locations. This study is used 8 inches diameter ball as the scale.

3.1. Quarry Selections

One of the main objective of this study was to select potential quarry sites and to characterize the rock for blasting tests. The study area is located in Gampaha and Kegalle districts respectively in Western and Sabaragamuwa provinces. The quarry site selection criteria was formulated by incorporating factors such as, slope of quarry rock face, rock type and degree of weathering. The six quarry sites were evaluated for their suitability. See table-3 for selected quarry locations. Further, selected rock sample representatives from quarry sites were collected and test for physical and mechanical properties.

Table-3: Selected quarry locations and rock types.

Quarry location	Rock characteristics
No. 01. Kegalle.	Quartz feldspar fine grain, light colourbiotite rock with banding. (leucocratic rock) Aggregate Impact Value (AIV) is 30 Location Coordinates: 230873N, 158031E
No, 02. Warakapola.	Massive charnockite (fine grain) rock. Aggregate Impact Value (AIV) is 22 Location Coordinates: 222884N, 136598E
No. 03. Deraniyagala.	Banded charnockite (fine grain) rock. (Charnockite with occasional banding and 5% > garnet.) Aggregate Impact Value (AIV) is 22 Location Coordinates: 195006N, 149038E
No. 04. Awissawella.	Medium grain size charnockite rock with banded appearance. Aggregate Impact Value (AIV) is 28 Location Coordinates: 211125N, 142884E
No. 05. Diulapitiya.	Banded biotite gneiss rock with 5% > garnet. Foliations are not well developed. Aggregate Impact Value (AIV) is 27 Location Coordinates: 231075N, 124322E
No. 06. Kegalle.	Banded biotite gneiss rock with well develop foliation. Aggregate Impact Value (AIV) is 32 Location Coordinates: 219866N, 153129E

3.2. Blasting parameters

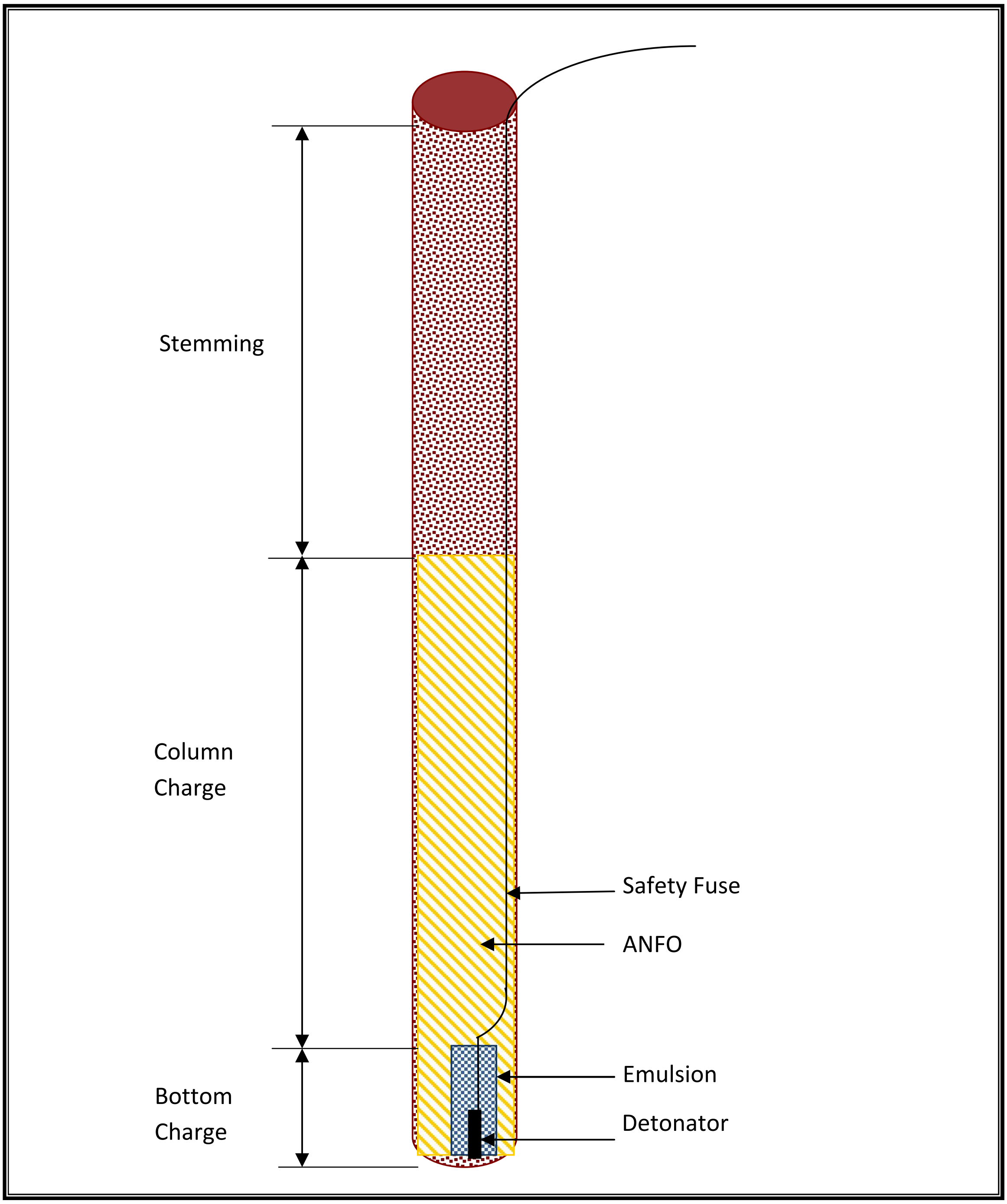

Figure - 5. Blast hole charging method

Single blast hole design is explained in *Figure - 6.*

Drill Hole Diameter- D

Hole Depth- H

Bench Height- L

Sub Drilling-U

Plain Detonators-PD

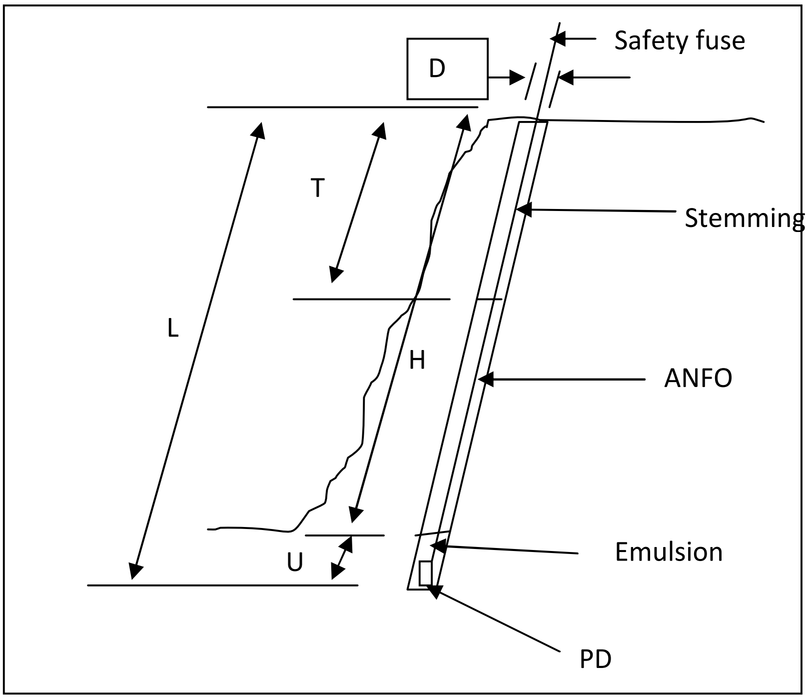

Figure - 6. Blast hole parameters

3.2.1. Bore hole charging

Six numbers of bore holes are drilled with diameter of 38mm and 1.524m depth. The explosives will be loaded according to Table-4 with plain detonator.

Table - 4: Parameters of bore hole charging.

Description	Parameters of Bore hole
Diameter of Bore Hole (mm)	38
Depth of Bore Hole (m)	1.524
Burden (m)	0.914
Stemming (m)	0.6096
Emulsion (Kg)	0.13
Ammonium Nitrate (kg)	0.35
Plain detonator (No)	01

3.2.2. Detonation velocity (VOD) of emulsion

Dautriche method was used to test for Velocity Of Detonation, (VOD) of using emulsion. This simple method does not require the use of any special and costly instruments. This method is an indirect field test method for suggesting VOD of explosives and the determination of the VOD is based on the fact that processes that propagate at different linear velocities travel different distance, in the same time interval. In essence, two ends of a piece of detonating cord are inserted some distance apart into a column of high explosive, such as stick of emulsion. When the explosive is detonated, by using No.8 detonator, that shock wave propagates along its length, first encountering and initiating one end of the detonating cord. Then after the shock wave in the explosive has propagated further, it encounters and initiates the other end of the detonation cord. At this time there are two shock waves propagating along the detonating fuse, one from each ends.

If the detonating fuse has been laid along the surface of a aluminium plate, the point where the two shock waves eventually collide will be witnessed by the aluminium plate as a scratch. If the VOD of the detonating cord, the distance between the points where the cord was inserted into explosive column and the distance from the midpoint of the cord to the point of collision of the two shock waves, are all known, then the unknown VOD of the column can be calculated using *equation-03*. [Source - Indian Standard, Method Of Test For Commercial Blasting Explosives And Accessories, Part II Explosives, Section I Explosives, General].

3.2.3. Dautriche (D'Autriche) method

The time lag between the initiation of two ends of a length of detonating fuse of known velocity of detonation (6500 ms^{-1}), inserted radially into an emulsion explosive cartridge at a known distance (d = 10 cm) apart, causes the two detonation fronts travelling in opposite direction along the length of the detonation fuse to meet at a point (L) away from the centre of the detonating fuse. Knowing the distance (d = 10 cm), the velocity of detonation (V_0 = 6500 ms^{-1}) of the detonation fuse, the velocity of detonation (V) of the emulsion explosive is calculated. The arrangement is shown in *Figure-7.1*. [Source - Indian Standard, Method Of Test For Commercial Blasting Explosives And Accessories, Part II Explosives, Section I Explosives, General].

3.2.3.1. The preparation to the test

Take a aluminium plate of 30cm length, 2.5cm width and 1cm thickness. Take the plate and make a scratch along the width near one end of the plate. Get a 2m length of detonating fuse of known velocity of detonation (VOD), mark its middle point and seal the ends using cello tape. Lay the detonation fuse of the aluminium plate in such a way that the centre of the detonating fuse is in line with the scratch on the aluminium plate. Make a hole at one end of the emulsion cartridge using brass or aluminium pricker for inserting the detonator. Make two radially driven holes of equal depths into cartridge at a known distance apart in such a way that the first hole at least 1.5 times the diameter of the cartridge away from the detonator end of the cartridge. Detonating cord's ends fix with the emulsion stick and plate.

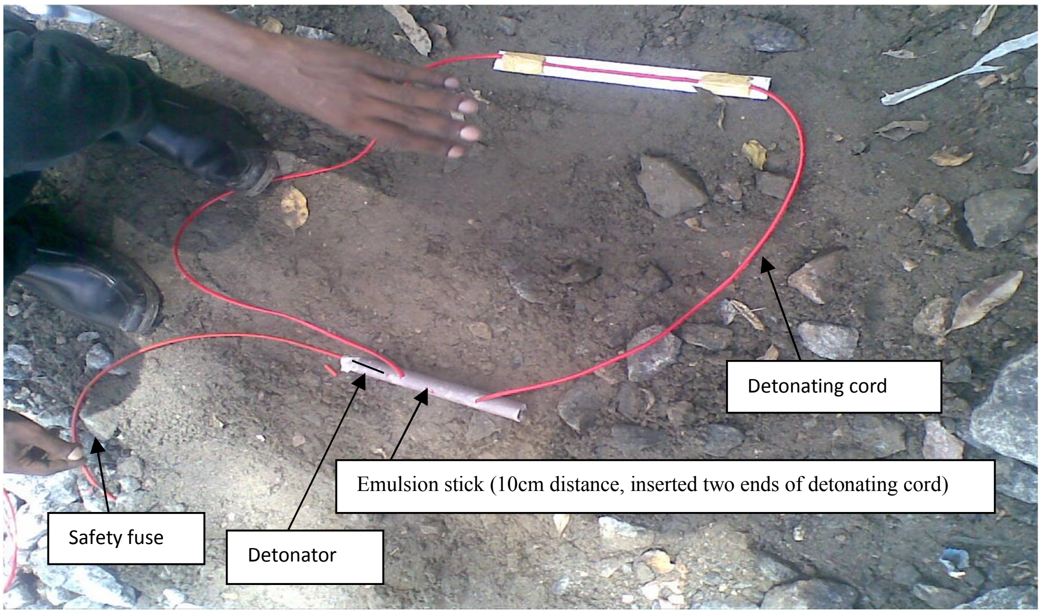

Figure-7.1: Sketch for the preparation to test the VOD by Dautriche method

Insert ends of detonating fuse into the radially drives in such a way that the longer arm of the detonating fuse protruding out of the aluminium plate is inserted into the nearer to the detonator end of the cartridge.

Firing by safety fuse, use a freshly cut 1m length of safety fuse, crimp a No:8 detonator to the fuse and then insert the detonator into the end hole of the emulsion cartridge. Fire the shot. After blasting the explosives cartridge of unknown VOD collect the aluminium plate and measure the length L that is the distance of the meeting of the two detonation front from the centre of the detonating fuse. (The point where two detonation fronts meet on the aluminium plate is distinguished by sharp mark appear on the plate). *Figure-7.2* illustrates it.

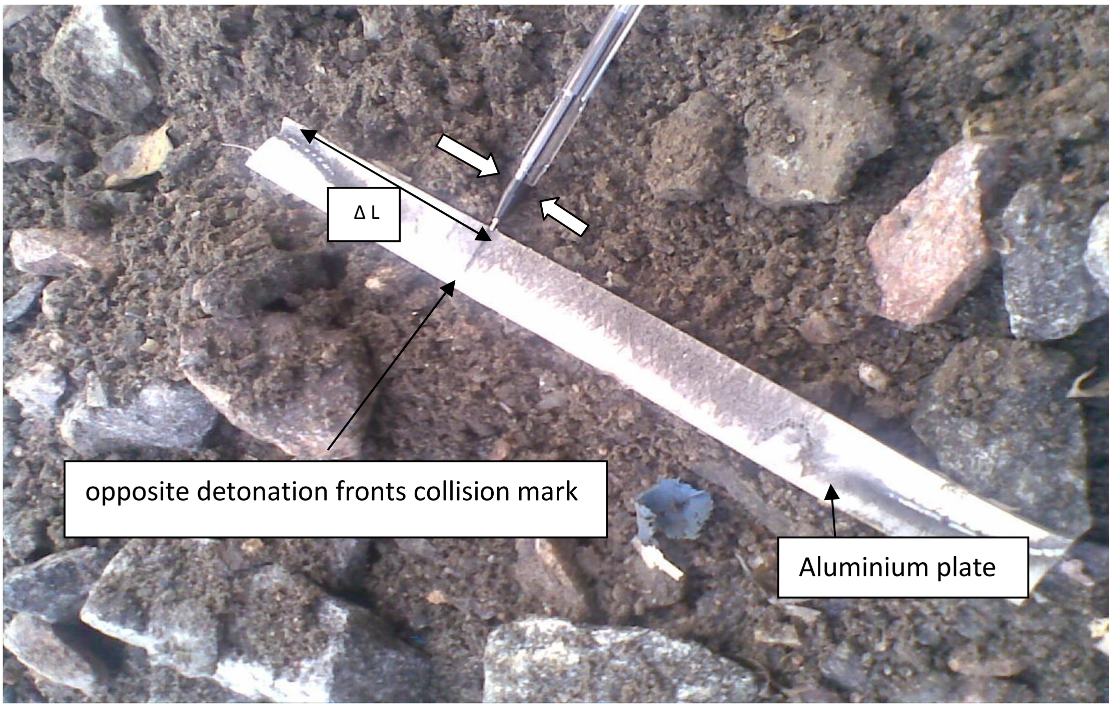

Figure-7.2: The distance from middle mark of detonating cord tocollision mark on the plate. (ΔL = off centre distance of plate)

3.2.3.2. Calculation of Velocity of Detonation (VOD)

$$\text{Velocity of Detonation of emulsion, } (VOD_{Emulsion}) = \frac{d \times V_0}{2\Delta L} \quad \ldots\ldots\ldots\ldots(03)$$

Where,

d = distance between two ends of the detonating fuse, (known = 10cm).

V_0= velocity of detonation of the detonating fuse, (known = 6500ms^{-1})

ΔL = distance between middle point of standard detonating fuse, (scratch on the aluminium plate) to the point on the aluminium plate where the twodetonation fronts traveling in opposite direction meet.

An average was taken of the three field tests as the Velocity of Detonation of used Emulsion is as follows.

[Source - Indian Standard, Method Of Test For Commercial Blasting Explosives And Accessories, Part II Explosives, Section I Explosives, General.]

3.2.3.3. Test Results of Emulsion VOD

Field application was conducted in SENOK mine, Kotadeniyawa

Table - 5: VOD of Emulsion

	ΔL - distance	VOD	Average VOD
Test-1	7.1 cm	4577.46 ms^{-1}	4361.09ms^{-1}
Test-2	7.9 cm	4113.92 ms^{-1}	
Test-3	7.4 cm	4391.89 ms^{-1}	

$VOD_{\textbf{Emulsion}}$ = 4361.09 ms^{-1} ....(04)

3.3. Laboratory strength tests for selected rock types

In the design of rock structure for civil engineering works such as dam foundations or vertical mine shafts, the deformation of the rock is of prime importance since excessive deformation may result in failure of the structures. On the other hand, the stability of rock structure, such as tunnels, open pit or underground excavations is dependent upon the strength and failure characteristic of the rock. The following laboratory tests are important to determine the rock characterization and strength behavior for civil engineering works. The sample collection and transportation, specimen preparation, test conducting, results tabulating are very important.

3.3.1. Aggregate impact value (AIV) test

The AIV test is carried out to evaluate the resistance to impact of aggregates. To assess the resistance of an aggregate to mechanical degradation, (toughness) is important. In the aggregate is weak, some degradation may take place and result in a change grading and the production of excessive undesirable fines. Aggregates to be used for wearing course, the impact value should not exceed 30 percent.

The apparatus consist of a steel test mould with a falling hammer as shown in *Figure-8*. The hammer slides freely between vertical guides so arranged that the lower part of the hammer is above and concentric with the mould. The material used is aggregate passing a 12.50mm IS sieve and retained on a 9.52mm sieve. The aggregate should clean and dried in 4 hours at 110 ^{0}C without damaging the aggregates.

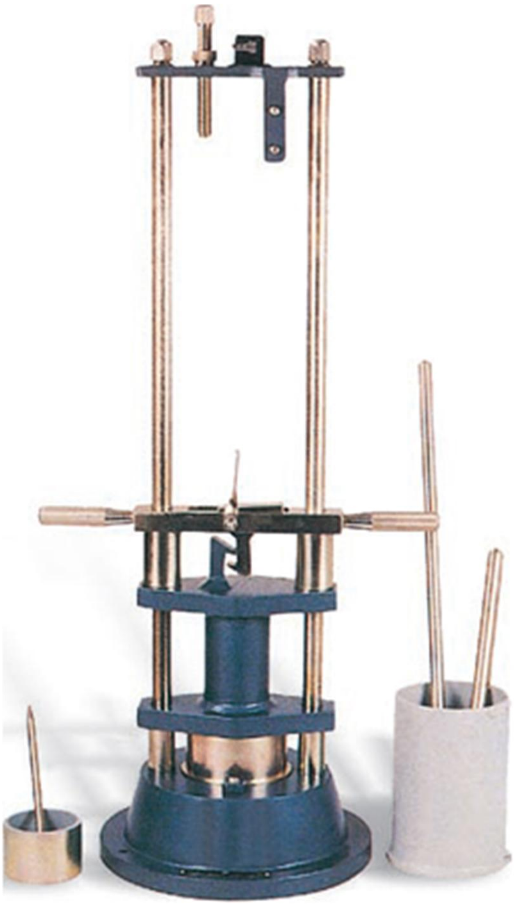

Figure-8: Aggregate impact tester

[Source- http://www.enkaymachine.com/productsdetail.php?cat=Ng==&product= MjYy . Abrasion: Ref. standards IS:2386 part (4), BS:812, ASTM C-131, D2, AASHOT T96]

The whole of the sample should be weighed (Mass A) is placed in the steel mould and compacted by a single tamping 25 strokes of the tamping rod (10 mm diameter, and 230 mm long). The test sample is subjected to15 blows of the hammer of 13.75 kg mass, which can be raised and allowed to fall freely through 380 ± 5mm with locking arrangement, each being delivered at an interval not less than one second. The crushed aggregate is sieved over a 2.36mm IS sieve. The fraction passing 2.36mm is weighed to the nearest 0.1g (Mass B). The fraction retained on the sieve is also weighed (Mass C). If [A-(B+C)] >1g, the result shall be discarded and fresh test made.

The Aggregate Impact Value (AIV) is,

$$AIV = \frac{B}{A} \times 100\,\% \quad \text{...(05)}$$

Where,

B = weight of fraction passing 2.36 mm IS Sieve

A = weight of oven dried sample.

An average is taken of the two tests and the result is recorded to the nearest whole number. [Source - Operation manual - ENKAY AGGREGATE IMPACT TESTER]. ASTM standard test method C-131

Reporting;

a.) Date on the sampling

Project name, Location, Sample number, Date of sampling

Type of sample, disturbed sample.

Sample transportation and storage condition

b.) Date on the testing

3.3.2. Uniaxial compression test

In the study of materials strength, compressive strength is the capacity of a material to withstand loads tending to reduce size, as opposed to tensile strength, which withstand loads tending to elongate. *Figure-9* is described it. In other words, compressive strength resists compression (being pushed together), whereas tensile strength resist tension (being pulled apart). When a specimen of material is loaded in such a way that its extends, it is said to be tension, on the other hand, if the material compresses and shortens it is said to be in compression. The test is mainly intended for using strength classification and characterization of intact rock. [Source - Rock and aggregate laboratory manual, geotechnical Laboratory, DGM, Thimphu, Bhutan. International Society for rock mechanics suggested methods "Rock Characterization, testing and Monitoring" Editor E.T.Brown, Pergamon Press 1981, Page 113 to 114].ASTM Standard Test Method D2938.

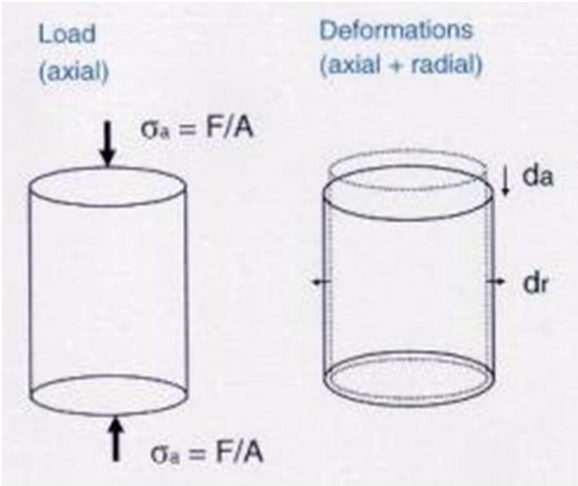

Figure-9 : Applied loads with materials deformations
Source - internet.

σ_a= F/A ....(6)

where;

σ_a = stress or uniaxial compressive strength, (Nm^{-2} = Pascal, Pa),

F = applied force or maximum load on the specimen (N),

A = area (m^2),

A = πr^2 , r = d/2, d = diameter of rock specimen (m)

By definition, the ultimate compressive strength of a material is that value of uniaxial compressive stress reached when the material fails completely. Prior to the yield point the material will deform elastically and will return to its original shape, when the applied stress is removed. Once the yield point is passed, some fraction of the deformation will be permanent and non-reversible, up to this amount of stress, stress is proportional to strain (hook's law), so that the stress-strain graph is a straight line, and the gradient will be equal to the elastic module of the material. Beyond the elastic limit, permanent deformation will occur. *Figure-10.* The test is intended to determine stress-strain curves and Young's modulus and Poisson's ratio in uniaxial compression of a rock specimen of regular geometry.

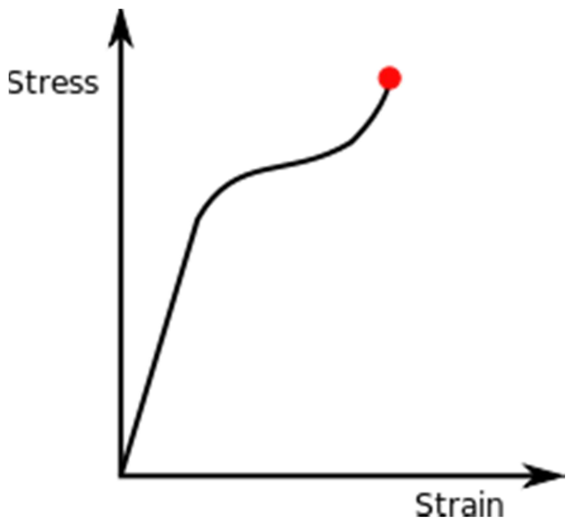

Figure-10 : Typical stress-strain curve (Hook's law).
Source - Internet

3.3.2.1. Core sample preparing to test

Specimen from drill cores are prepared by cutting them to the specified length and thereafter grinded and measured. There are high requirements on the flatness of the end surface in order to obtain an even load distribution. Recommended ratio of high/diameter of the specimen is between 2 and 3.

The specimen are loaded axially up to failure or any other prescribed level whereby the specimen is deformed and the axial and the radial deformation can be measured using a special equipment. Core samples preparation are in *Figure-11:1* to *11:12*. The uniaxial compressive strength of rock sample should be calculated by dividing the maximum load carried by the rock sample during the test, by the original stress area.

Core samples preparation are as below *Figure 11:1 to11:12* shown.

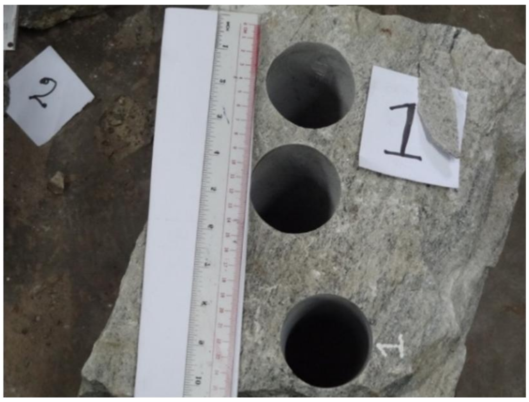

Figure - 11:1

Figure - 11:2

Figure - 11:3

Figure - 11:4

Figure - 11:5

Figure - 11:6

Figure - 11:7

Figure - 11:8

Figure - 11:9

Figure - 11:10

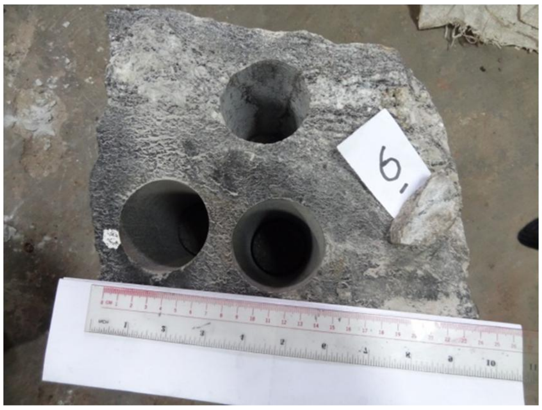

Figure - 11:11

Figure - 11:12

Figure - 11:13

Figure-12: Uniaxial unconfined compression tester. [Source - internet - http://www.enkaymachine.com/products detail.php?cat=Mg==&product=MTAw]

Reporting

a.) Date of sampling

Project name, Location, Sample number, Date of sampling.

Type of sample, Block

Sample transportation and storage condition

b.) Date of specimen

Form, Dimensions and weight of the specimen.

c.) Date of testing procedure

Type of testing machine used, loading rate.

Sketch of the mode of failure

3.3.3. Point load test

The point load strength test is intended as an index test for the strength classification of rock materials. It may also be used to predict other strength parameters with which it is corrected for example, uniaxial compressive strength and tensile strength.

The test measures the point load strength index, $I_{s(50)}$ of rock specimens and their strength Anisotropy Index, $I_{a(50)}$,which is the ratio of point load strengths in directions which give the greatest and least values. The test can be performed a laboratory testing machine**.** Point load test gives the point load strength index $I_{s(50)}$ which needs to corrected to the slandered equivalent core diameter, De, of 50mm if other specimen size are used.

A test sample is defined as a number of rock specimens of similar strength for which a single point load strength value is to be determined (preferably 10 specimens at least are tested from one sample). For diametrical tests the specimens should have a ratio of length to diameter which is greater than 1.0. For axial tests the core specimens should have a ratio length/diameter between 0.3 and 1.0. For routine testing and calcification, specimens should be tested either fully water-saturated or at their natural water content. The test should be rejected as invalid if the fracture surface passes through only one loading point.

The $I_{s(50)}$ is calculated by :

$I_{s(50)} = P/De^2$..(7)

Where:

P = the failure load in Newton (N),

De = the diameter in millimeter (mm).

The point load strength index, $I_{s(50)}$ can be transferred into uniaxial compressive strength, (UCS), using a linear conversion factor that need to be determined by a particular rock type.

UCS = k X $I_{s(50)}$..(8)

Where:

UCS = uniaxial compressive strength,

k = rock specific calibration constant

[Source - Rock and aggregate laboratory manual, geotechnical Laboratory, DGM, Thimphu, Bhutan."Suggested method for determining point load strength"int, Journal Rock Mech.Min.Sc. Vol.22,No.2,pp.51-60 1985].

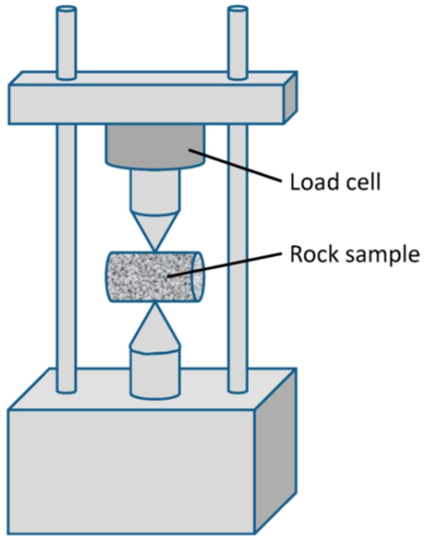

Figure-13 : Point load test
Source - Internet

Reporting

a.) Date of sampling

Project name, Location, Sample number, Date of sampling.

Type of sample, (Core, block, disturbed or other), sample dimensions.

Sample transportation and storage condition

b.) Date of specimen

Form, Dimensions and weight of the specimen.

c.) Date of testing procedure

Type of testing machine used, loading rate.

Sketch of the mode of failure

3.3.4. Brazilian tensile strength

Brazilian tensile strength is a geotechnical laboratory test for indirect measurement of tensile strength of rocks. In Brazilian test a disc shape specimen of the rock is loaded by two opposing normal strip loads at the disc periphery. *Figure-14.*

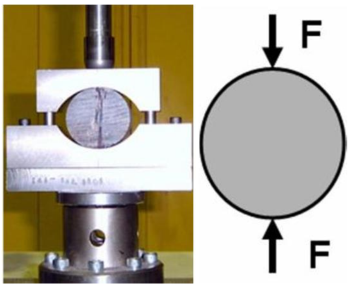

Figure-14 : Load applied for indirect tensile strength test.
Source - Internet

The specimen diameter shall preferably be not less than NX core size (54mm) or at least ten times the average grain size. The thickness/diameter ratio should be 0.5 to 0.6. The load is continuously increased at a constant rate until failure of the sample occurs within few minutes. The loading rate is depending on the material and may from 10-50 kN/min. At the failure, the tensile strength (σt) of the rock is calculated by,

$$\sigma t = \frac{2P}{(\pi DL)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Where:

σt = Tensile strength (Mpa)
P = Maximum load at failure (MN)
D = diameter of the specimen (m),
L = thickness of the specimen (m)

The above equation uses the theory of elasticity for isotropic continuous media and gives the tensile stress perpendicular to the loaded diameter at the centre of the disc at the time of the failure. If the sample rock is anisotropic and exhibits weakness planes (preferred orientation of minerals or stress history), the specimen should be prepared in such a way that both directions parallel as well as perpendicular to such planes can be tested.(axis of the cylinder parallel to the plane). At least ten specimens should be taken from one sample to obtain a meaningful average.

Reporting

a.) Date of sampling

Project name, Location, Sample number, Date of sampling.

Type of sample, (Core, block, disturbed), sample dimensions.

Sample transportation and storage condition

b.) Date of specimen

Form, Dimensions and weight of the specimen.

c.) Date of testing procedure

Type of testing machine used, loading rate.

Sketch of the mode of failure

[Source -International Society for rock mechanics suggested methods "Rock Characterization, Testing And Monitoring" Editor E.T,Brown, Pergamon Press1981,pages 119 to121, ASTM Standard Test Method D3967-81].

3.3.5. Los Angeles Abrasion Value test (LAAV)

Abrasion test is carried out to test the hardness property of aggregates. Maximum abrasion value of 40 percent is allowed.

$$\text{Los Angeles Abrasion Value} = \frac{\text{Weight of fraction passing 1.7 mm IS sieve}}{\text{Weight of total materials}} \text{X100} \quad ..... (10)$$

The sample is selected of clean aggregate and oven dried at 105 - 110 ^{0}C for four hours and after removing the sample and allow to room temperature to cool. After cooling to room temperature, sample is measured to exact quantity of weight. Then sample is put into the LAAV test machine. There are several LAAV grading types with the selection of abrasive charge depending on the composition of the test sample a number of 6 to 12 steel balls has to be added to the sample. The steel balls shall have a diameter of 46 to 47.6 mm and weight between 390 and 445g. That the machine is selected to 500 revolutions for grading A, B, C, or D and to 1000 revolutions for grading E, F, or G. The revolution times, are as at table-6.

ASTM Standard Test Method C131 - 96

Table-6 : LAAV grading and abrasive charge weight of number of balls.

Selection of Abrasive Charge		
Grading	**No. of steel balls**	**Weight of charge (g)**
A	12	5000 ± 25
B	11	4584 ± 25
C	8	3330 ± 25
D	6	2500 ± 25
E	2	5000 ± 25
F	12	5000 ± 25
G	12	5000 ± 25

Usually the abrasiveness must be determined before the aggregate is sieved and recombined to the grading at which it will be used. Table-7 describes a limited number of test sample grading. That grading of the test sample must be chosen which is closest to the grading of the sieved and mixed aggregate as it will be used. By sieving and combination of fraction of the original sample the test sample must be prepared.

For grading A,B,C and D that the LAAV test machine rotate 500 revolution if the grading E,F and G, rotate it for 1000 revolution. Discharge all the material from the cylinder and sieve the sample on the 1.7mm IS sieve until not more than a trace passes the sieve during 2 minutes. Collect the material coarser than 1.7 mm IS sieve. Washed and dry the material at 1050C to 1100C to substantially constant weight. Weight is accurately to the nearest gram. [Source - Rock and aggregate laboratory manual, geotechnical Laboratory, DGM, Thimphu, Bhutan.ASTM Standard Test Method C131 - 96].

Table-7: LAAV Grading of test samples

Sieve size		**Weight of test samples for size grading (g)**						
Passing (mm)	**Retained (mm)**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
80	63					2500		
63	50					2500		
50	40					5000	5000	
40	25	1250					5000	5000
25	20	1250						5000
20	12.5	1250	2500					
12.5	10	1250	2500					
10	6.3			2500				
6.3	4.75			2500				
4.75	2.35				5000			

Figure-15: Los Angeles Abrasion Testing Machine.

[Source - Internet,http://www.enkaymachine.com]

3.3.6. Specific Gravity test

The specific gravity of aggregates normally used in road construction ranges from about 2.5 to 2.9 and water absorption value range from 0.1 to about 2.0 percent for aggregates normally used in road surfacing. Specific gravity can be defined as the ratio of the weight of aggregate in air to the equal volume of water displaced by saturated surface dry aggregate. [Source - Internet - The constructor civil Engineering Home. https://theconstructor.org/building/building-material/specific-gravity-and-water-absorption-test/1358/].

The coarse aggregate specific gravity test is used to calculate the specific gravity of a coarse aggregate sample by determining the ratio of the weight of a given volume of aggregate to the weight of an equal volume of water. The standard coarse aggregate specific gravity and absorption test - ASTM C127.
[Source- http://www.pavementinteractive.org/coarse-aggregate-specific-gravity/].

Specific gravity is a measure of a material's density as compared to the density of water at 23^0C. By definition water at a temperature of 23^0C has a specific gravity of 01. Obtain a sample of course aggregate material retain on the No. 4 (4.75 mm) sieve. This sample size is based on nominal maximum aggregate size (NMAS). Sample size is range from 2000g for a 0.5 inch (12.5mm) NAMS to 5000g for a 1.5 inch (37.5mm) NAMS.

Wash the aggregate retained on the No. 4 sieve. Dry the material in an oven at 110^0C until it maintains a constant mass. This indicates that all the water has left the sample. Cool the aggregate to a comfortable handling temperature.

Immerse the aggregate in water at room temperature for a period of 15 to 19 hours. Dry the sample to a saturated surface dry (SSD) condition. Rolling up aggregate into the towel and then shaking and rolling the aggregate from to side to side be usually effective in reducing the sample to a SSD condition. It may be necessary to wipe the larger particles separately. Once there are no visible signs of water film on the aggregate particle surfaces, determine the sample mass.

Place the entire sample in a basket and weight it under water. Shake the container to release any entrapped air before weighting. The container overflow needs to work properly to compensate for the water displaced by the sample. Remove the aggregate from the water and dry it until it maintains a constant mass. This indicates that all the water has left the sample. Dry should occur in an oven regulated at 110^{0}C.

$$\text{Specific gravity} = \frac{D}{C - (A-B)} \qquad \text{...} \; (11)$$

Where :

D = weight of oven dried sample

A = (weight of pycnometer + sample + water)

B = (weight of pycnometer + water)

C = (weight of saturated and surface dried aggregate

3.3.7. Porosity of rock

Porosity (n), is defined as a ratio of pores volume, (V_v), to bulk volume (V), of a reservoir rock. The test is conducted to rock specimens of cylindrical or other regular forms. If irregular samples are used the volume can be determined by measurement of the saturated - submerged mass and the saturated mass of the samples.

$$\text{Porosity (n)}, \; n = \frac{Vv}{V} \times 100\% \qquad \text{...} \; (12)$$

$$\text{Pore Volume (Vv)}, \; V_v = (V - Vs) \qquad \text{...} \; (13)$$

V_S is volume occupied the solid grains of the rock. The pore space in reservoir rocks are must frequently the inter granular space between the sedimentary particles. Total porosity includes all existing pores regardless of whether they are connected or not. Effective porosity only includes the inter connected pores.

The specimen mass should be at least 50g and a cube of 3x3x3 cm^3 or a cylinder with a diameter of 2.5cm and a length of 5cm. The specimen bulk volume (V) is calculated from the average value of at least 3 caliper readings with the accuracy of 0.1mm for each dimension of the specimen. The specimen is saturated by water immersion in a vacuum of less than 800Pa for a period of at least 1 hour, with periodic agitation to remove trapped air. The specimen is removed from the water and surface dried using moisten cloth, care being taken to remove only surface water and to ensure that no fragments are lost. The specimen is located in a container to avoid loss of mass during subsequent sample handling. The mass of specimen plus container (B) is determined with an accuracy of 0.01g. The specimen with in open container is dried 24 hours in oven at 105^0C temperature. After closure of the container and cooling in a desiccator for 30 minutes. The mass (C) of the dry sample with the container and lid is measured with an accuracy of 0.01g. The dry mass of container and lid (A) is determined with an accuracy of 0.01g.

Saturated surface dry mass = B - A ……………………………………(14)

Dry specimen mass = C - A ……………………………………(15)

Pore Volume (Vv), $$Vv = \frac{(B\text{-}A) - (C - A)}{\text{Density of water}} \quad \ldots\ldots(16)$$

Porosity (n), $$n = \frac{Vv}{V} \times 100\% \quad \ldots\ldots (17)$$

[Source -International Society for Rock Mechanics Suggested Methods "Rock Characterization, Testing And Monitoring" Editor E.T,Brown, Pergamon Press1981,pages 81 to 85. ASTM Standard Test Method C97-83].[Rock and aggregate laboratory manual, Geotechnical Laboratory, DGM, Thimphu, Bhutan].

3.4. Issues Of Significance

Above described field tests were done in the selected quarries. The economic analysis of the use of explosives is an important part of blasting operations in mining field. Fragmentation, muck pile displacement, muck pile profile, ground vibration, air blast over pressure, back and side spills, and fly rocks are the visual characteristics have to be evaluate for blasting practice. Explosive reaction is released energy, and the efficient use of this energy is a major factor in keeping rock blasting costs. The energy of explosives enhances the fragmentation, which ultimately produces a positive effect on production costs. The degree of fragmentation and movement of obtained machineries are directly related to the amount of operation cost.

Analysis of the blasting, that the explosive energy be placed into drill hole of different hardness rock types. Proper choice of energy can produce better fragmentation and better rock volume.

CHAPTER - 4

4. FIELD APPLICATION OF EMULSION EXPLOSIVES IN HARD ROCK FORMATION

4.1. Selected quarry location-01

Quarry Address - Diyagama, Hiriwdunna.
District - Kegalle
Divisional Secretariat - Kegalle
Coordinates - 230873N, 158031E

Quarry site is situated at Diyagama village and it is called Galkotuwawatta. In order to reach the quarry, one has to turn to left from the Karandupana junction, and proceed along the Rambukkana road. Karandupana junction is located 1km away from Kegalle town of Colombo-Kandy main road. After proceeding about 2.5 km distance along the Rambukkana road, Diyagama junction is identified and turn right and go straight to 1.5km and then road is appeared to left into the land with culvert crossing small canal.

*figure-16:*Rock Sample, Quartz feldspar fine grain, light colour biotite rock with banding (leucocratic rock).

4.1.1. Selection of rock surface and preparation for testing at location-01

Carefully selected the good systematic, uninterrupted, no weathered surface without joints, fractures, structural discontinuities, or cracks. Selected area has enough solid surface to blast and has to be cleaned.

4.1.2. Field Application Details at location-01

Each blast of blasted location 01 was compared with the scale to get the idea of fragmentation. That took place the photograph of each blast with ball scale and then can count the number of boulders with several boulder sizes. The fly rock thrown distance of each blast was higher value and average value can be calculated. Details were in *Figures from 16.1 to 16.6.1.* The ball diameter is 20.32cm (8 inches). It was taken for scale to fragmentation size analysis to each photograph. See Table-9. for more details.

Figure-16.1: Location -01, Blast- 01 - (Scale: Ball Diameter is 20.32cm)

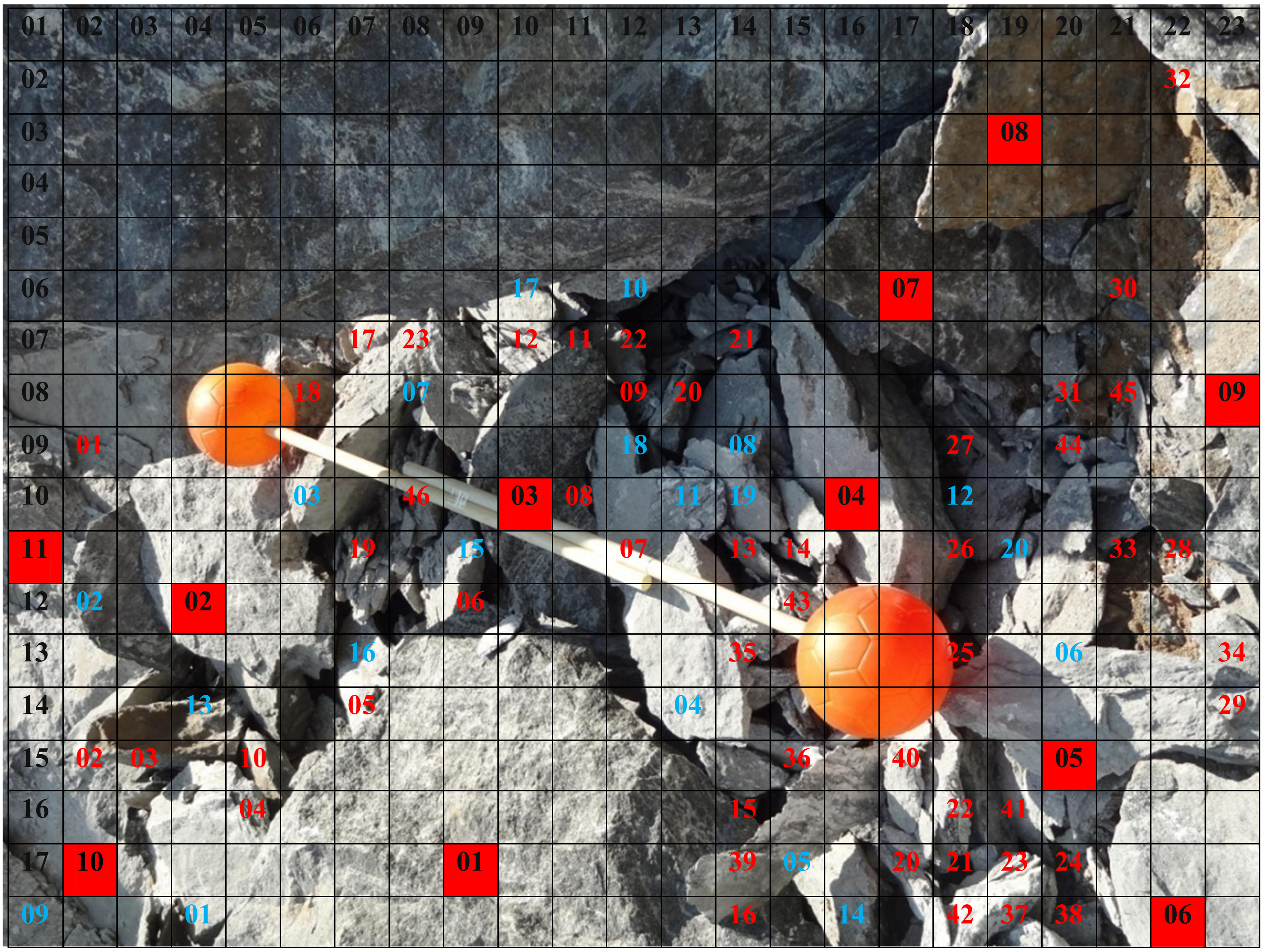

Figure-16.1.1: Location -01, Blast- 01, Fragmentation Analysis - (Scale - Ball diameter is 20.32cm)

Table- 8.1 :Fragmentation Analysis of Location -01, blast – 01 of *Figure-16.1.1*

Size of fragments(Inches)	Numbers of fragments	Average
1-6	63	45.000 %
6-9 (Red colour)	**46**	32.857 %
9-15 (Blue colour)	**20**	14.286 %
15< Boulders (Red Bold)	11	07.857%
Total	140	

Figure-16.2: Location -01, Blast -02 - (Scale: Ball Diameter is 20.32cm)

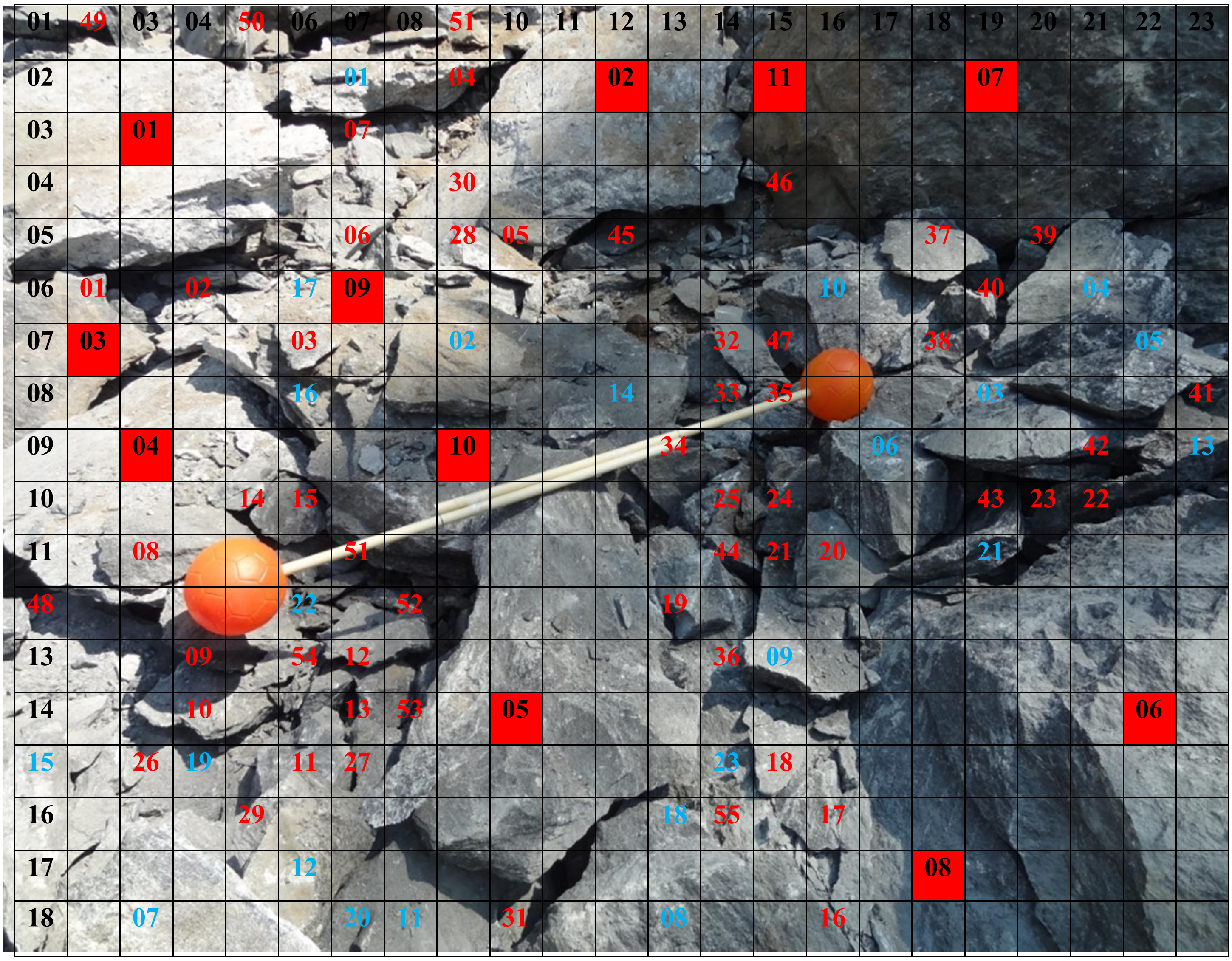

Figure-16.2.1: Location -01, Blast -02,Fragmentation Analysis -(Scale - Ball diameter is 20.32cm)

Table- 8.2:Fragmentation Analysis of Location -01,blast – 02 of *Figure-16.2.1*

Size of fragments(Inches)	Numbers of fragments	Average
1-6	96	51.892 %
6-9 (Red colour)	**55**	29.730 %
9-15 (Blue colour)	**23**	12.432 %
15< Boulders (Red Bold)	11	5.946 %
Total	185	

Figure-16.3 :Location -01, Blast -03- (Scale: Ball Diameter is 20.32cm)

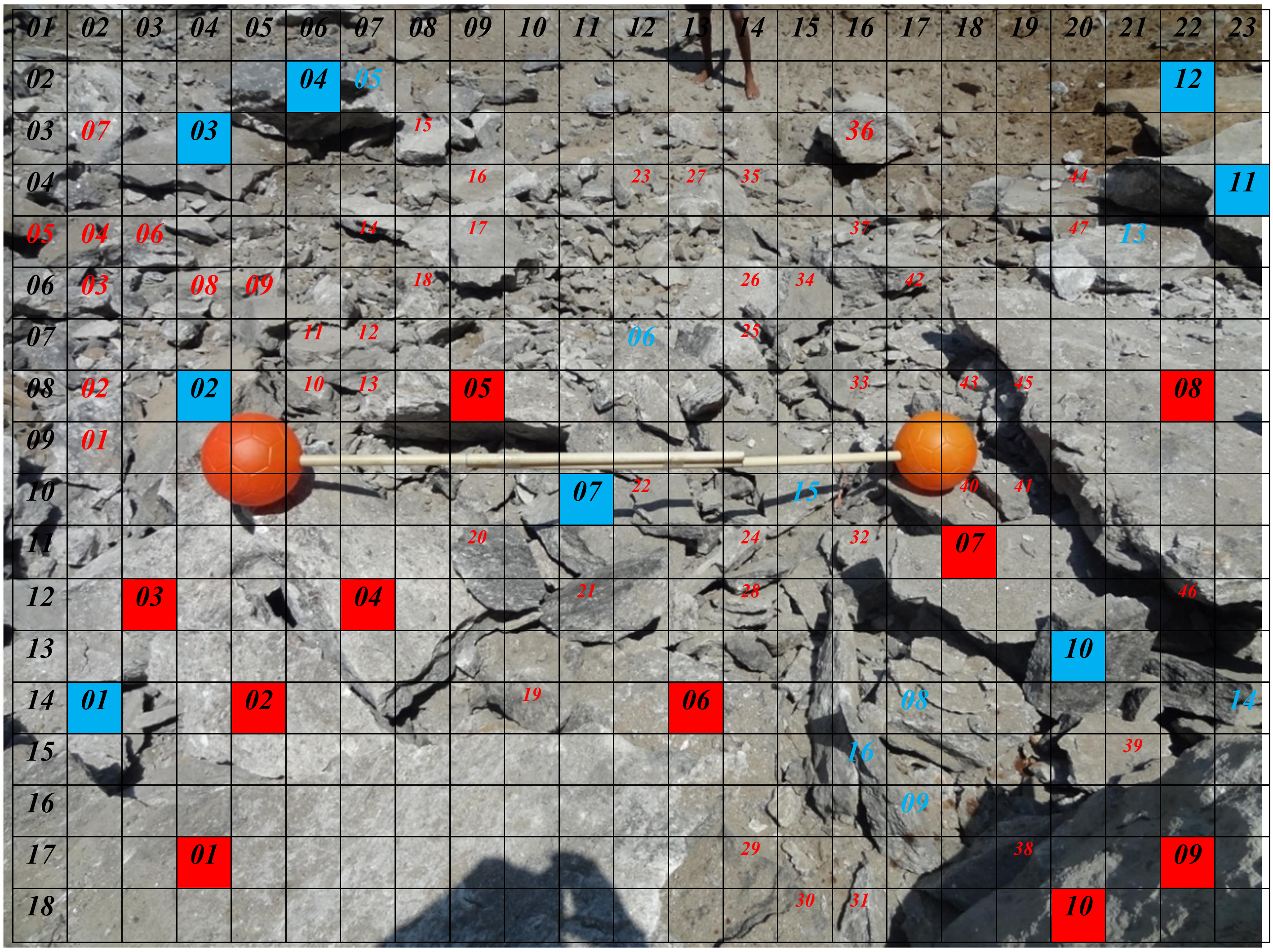

Figure-16.3.1: Location -01, Blast -03,Fragmentation Analysis -(Scale: Ball Diameter is 20.32cm)

Table- 8.3:Fragmentation Analysis of location -01, blast – 03 of *Figure-16.3.1*

Size of fragments(Inches)	Numbers of fragments	Average
1-6	388	84.165 %
6-9 (Red colour)	**47**	10.195%
9-15 (Blue colour)	**16**	3.47 %
15< Boulders (Red Bold)	10	2.169 %
Total	461	

Figure-16.4 : Location -01, Blast – 04 - (Scale: Ball Diameter is 20.32cm)

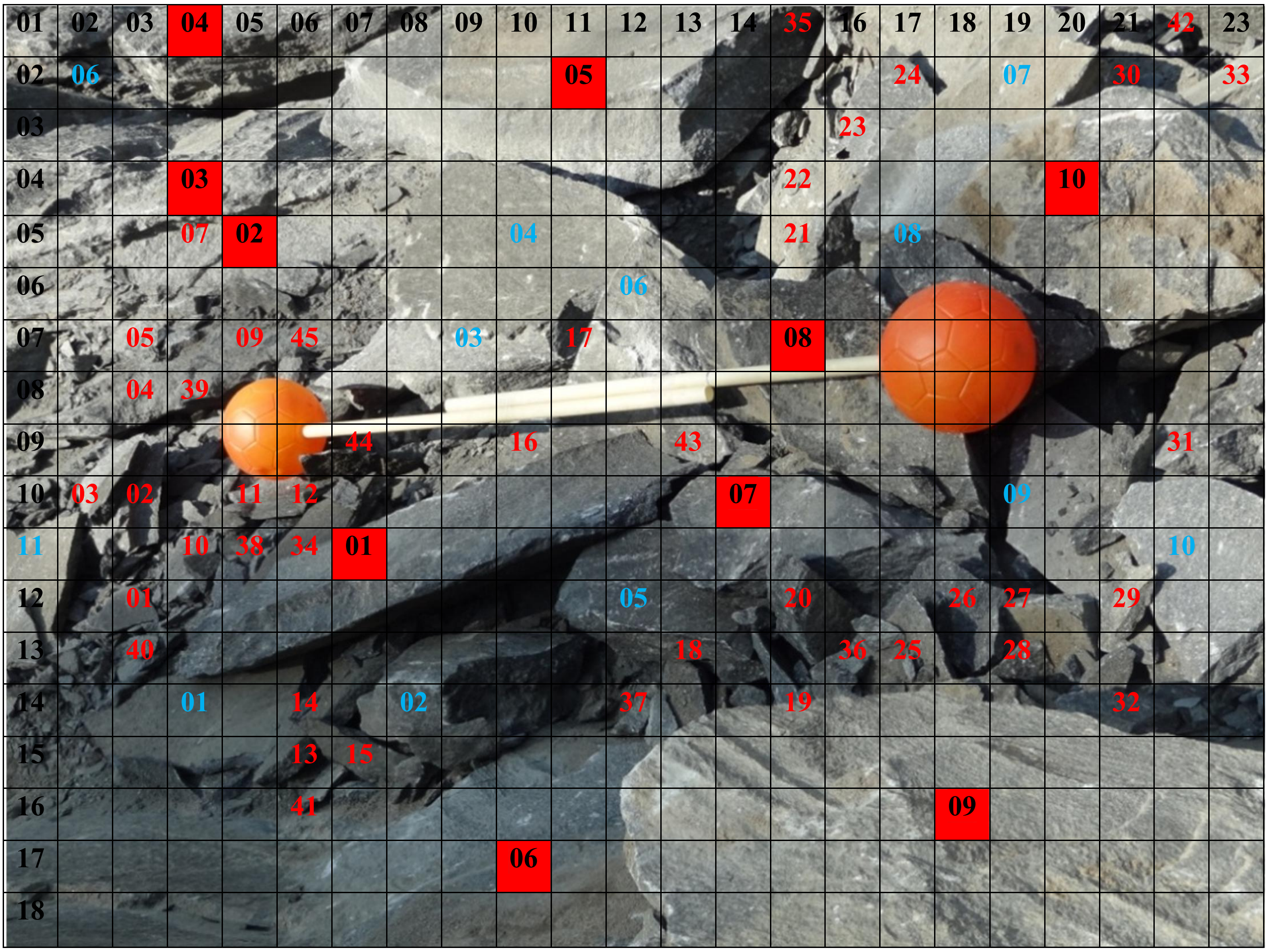

Figure-16.4.1: Location -01, Blast -04,Fragmentation Analysis - (Scale: Ball Diameter is 20.32cm)

Table- 8.4: Fragmentation Analysis of location -01 blast – 04 of *Figure-16.4.1*

Size of fragments(Inches)	Numbers of fragments	Average
1-6	113	63.128%
6-9 (Red colour)	**45**	25.140%
9-15 (Blue colour)	**11**	6.145%
15< Boulders (Red Bold)	10	5.586 %
Total	179	

Figure-16.5: Location -01, Blast – 05 - (Scale: Ball Diameter is 20.32cm)

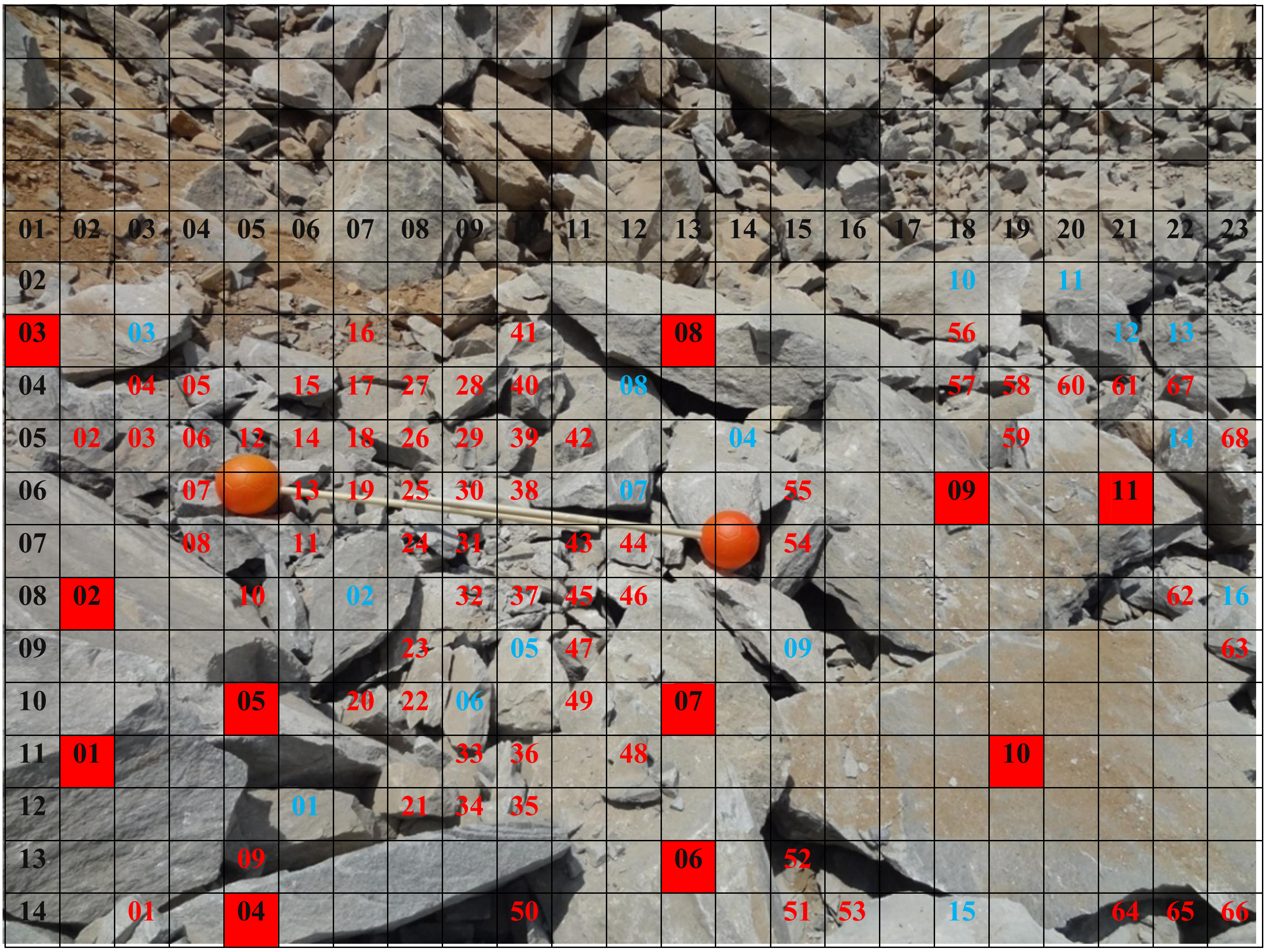

Figure-16.5.1 :Location -01, Blast -05,Fragmentation Analysis - (Scale: Ball Diameter is 20.32cm)

Table- 8.5: Fragmentation Analysis of location -01, blast – 05 of *Figure-16.5.1*

Size of fragments(Inches)	Numbers of fragments	Average
1-6	87	47.802 %
6-9 (Red colour)	**68**	37.363 %
9-15 (Blue colour)	**16**	8.791%
15< Boulders (Red Bold)	11	6.044%
Total	182	

Figure-16.6 :Location -01, Blast -06 - (Scale: Ball Diameter is 20.32cm)

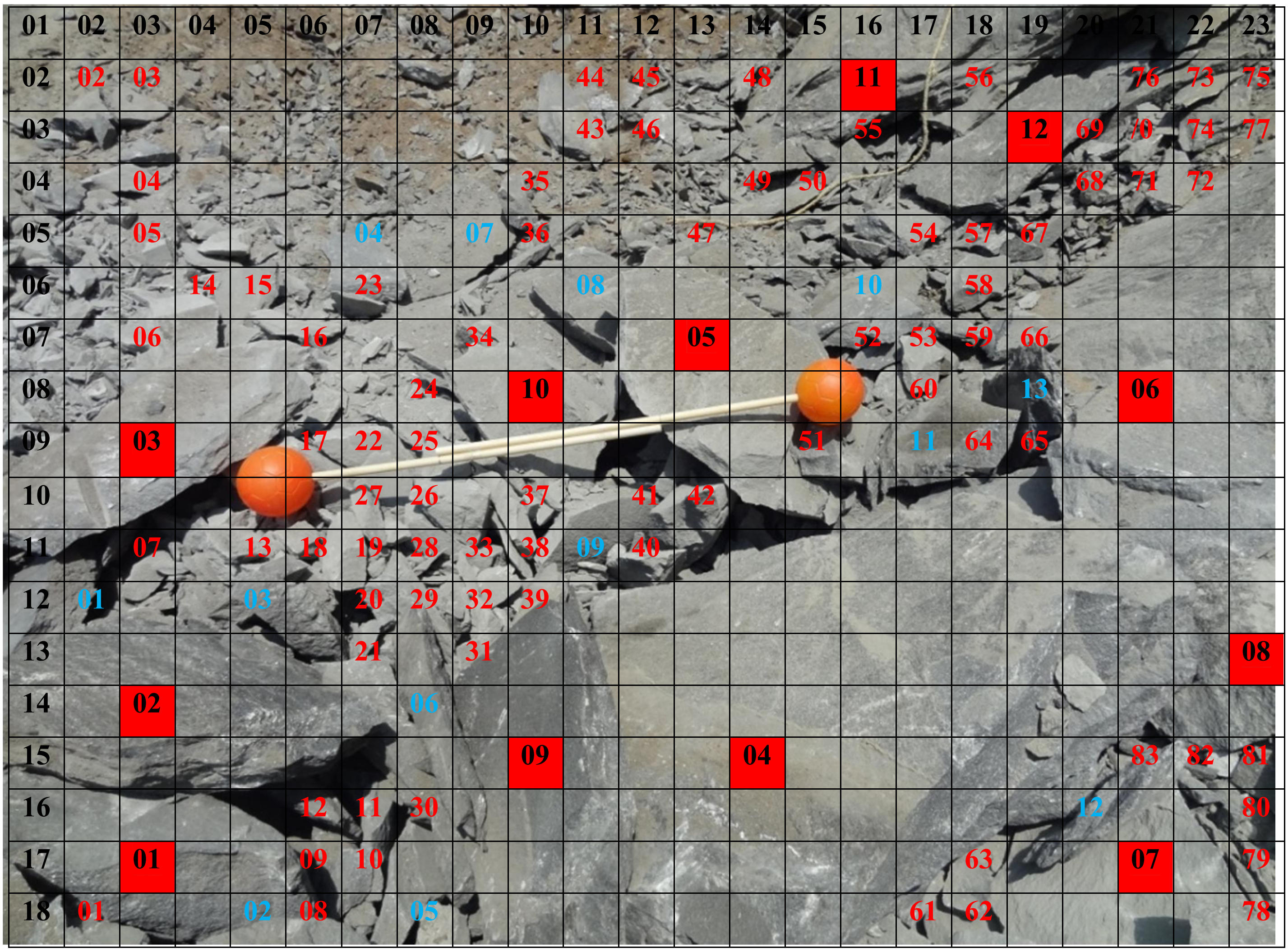

Figure-16.6.1: Location -01, Blast - 06,Fragmentation Analysis -(Scale: Ball diameter is 20.32cm)

Table- 8.6: Fragmentation Analysis of location - 01, blast – 06 of *Figure-16.6.1*

Size of fragments(Inches)	Numbers of fragments	Average
1-6	263	70.889 %
6-9 (Red colour)	**83**	22.372%
9-15 (Blue colour)	**13**	3.504 %
15< Boulders (Red Bold)	12	3.234%
Total	371	

Field application details are summarized as below Table-9, regarding the above location-01, six bore hole blasting.

4.1.3. Comparison of the blast location-01

Table-9 :The summary of Six boreholes blasting at location-01

Number of Borehole	**01**	**02**	**03**	**04**	**05**	**06**
Borehole diameter (mm)	38	38	38	38	38	38
Borehole depth (m)	1.524	1.524	1.524	1.524	1.524	1.524
Burden (m)	0.914	0.914	0.914	0.914	0.914	0.914
Emulsion (kg)	0.13	0.13	0.13	0.13	0.13	0.13
Plain Detonator (No.)	01	01	01	01	01	01
AN/FO (kg)	0.35	0.35	0.35	0.35	0.35	0.35
Stemming (m)	0.6096	0.6096	0.6096	0.6096	0.6096	0.6096
Explosive Column height (m)	0.914	0.914	0.914	0.914	0.914	0.914
Fly rock thrown distance-m	4	6	16	9	12	16
Fragment scattered area-m^2	6	6	12	6	12	12
Material quantity after blasting. (Cube)	2	2	1.5	2	1.5	1.5
Material quantity after blasting. (m^3)	5.66	5.66	4.248	5.66	4.248	4.248
Specific Charge (kg m^{-3})	0.14	0.14	0.19	0.14	0.19	0.19
Average blasted rock volume	4.956 m^3 (1.75 Cubes)					
Average Specific Charge	0.155 kg m^{-3}					

Average blasted rock volume = 4.956 m^3

Average solid rock volume = 4.956 m3 / 1.6

Average solid rock volume = 3.0975 m^3

Average Specific Charge = 0.48kg / 3.0975 m^3

= <u>0.155 kgm^{-3}</u>

4.2. Selected quarry location-02

Quarry Address - Dorawaka, Warakapola

District - Kegalle

Divisional Secretariat - Warakapola

Coordinates - 222884N, 136598E

Quarry site is situated at Ihalaweligalla village and land is called Atnawalawatta. In order to reach the quarry, one has to turn to right from the Warakapolatown of Colombo - Kandy main road, and proceed along the Anguruwella road. After proceeding about 2.5 km distance along the Anguruwella road, Dorawaka village is identified and turn right to Ihalaweligalla road and go straeight to 1.5km and then road is appeared to right to the land of Atnawalawatta quarry site.

Figure-17: Rock Sample - Massive charnockite (fine grain) rock.

4.2.1. Selection of rock surface and preparation for testing at location-02

Carefully selected the good systematic, uninterrupted, no weathered surface, without joints, fractures or cracks. Selected area has enough solid surface to blast. Clear to observe the blasting yield, thus remove all the muck files and clean the quarry, before doing the field application.

4.2.2. Field application details at location-02

To get the idea of fragments, that took the photograph of each blast with 20.32 cm ball (scale) and then can calculate the separation of boulder size or fragmentation and count the number of boulders. The fly rock thrown distance of each blast is significant value and average value is 5.2 m of location no. 02. Absorption of blasting energy to rock, most probably is consumed to production and fragmentation of the rock. For more details study the *Figures from 17.1 to 17.6.1.* and see the table-11 for more details. Detonation energy of Emulsion primer charge is highly adopted to the hardness of rock, therefore the production is the highest and input the maximum energy of primer charge to activate the rock breakage.

Figure-17.1: Location - 02, Blast – 01 - (Scale: Ball diameter is 20.32 cm)

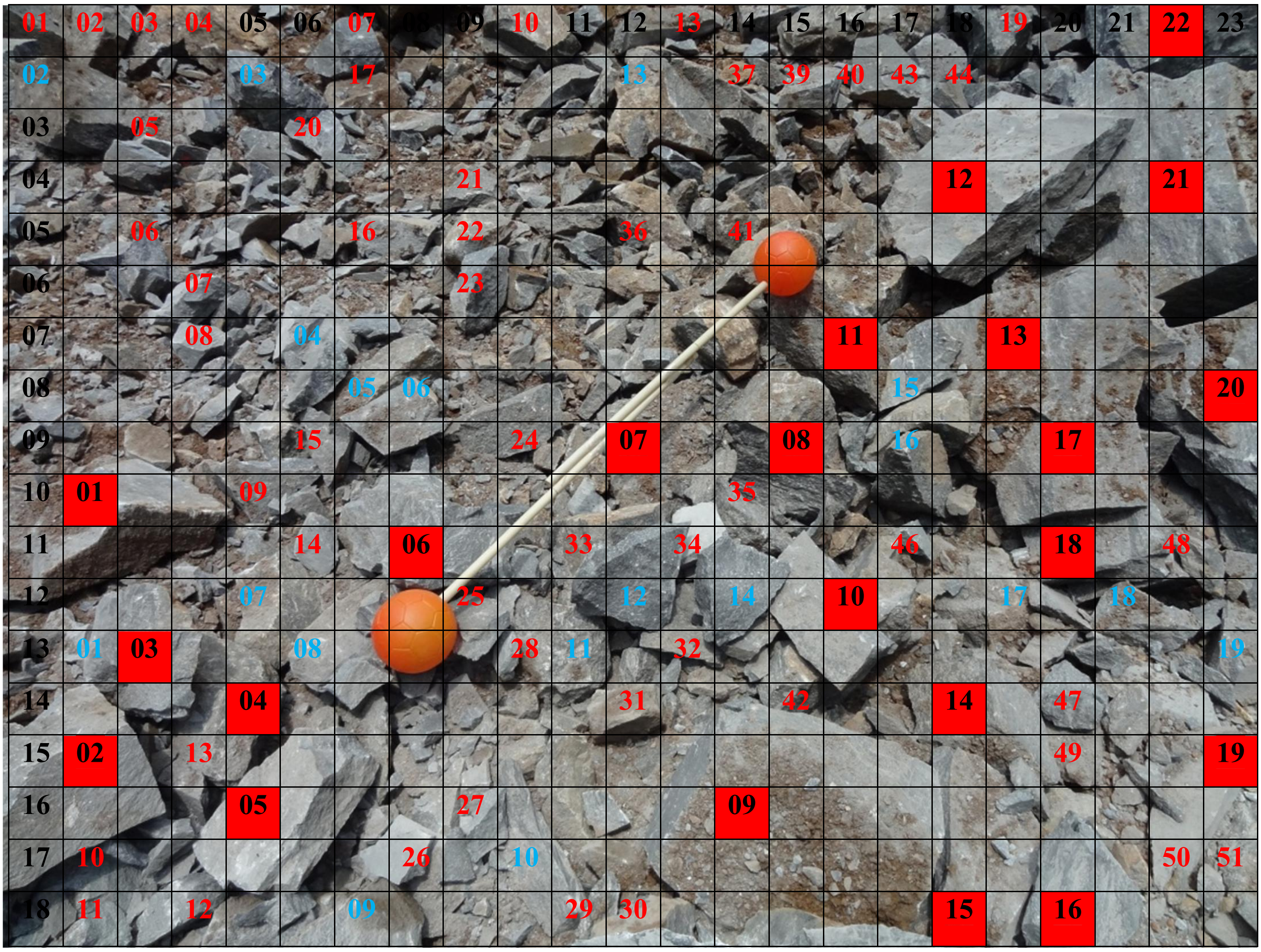

Figure-17.1.1: Location - 02, Blast -01 -Fragmentation Analysis (Scale : Ball diameter is 20.32 cm)

Table- 10.1: Fragmentation Analysis of location - 02, blast – 01 of *Figure-17.1.1*

Size of fragments (Inches)	Numbers of fragments	Average
1-6	580	86.309 %
6-9 (Red colour)	51	7.589 %
9-15 (Blue colour)	19	2.827%
15< Boulders (Red Bold)	22	3.273%
Total	672	

Figure-17.2: Location - 02, Blast -02- (Scale: Ball diameter is 20.32 cm)

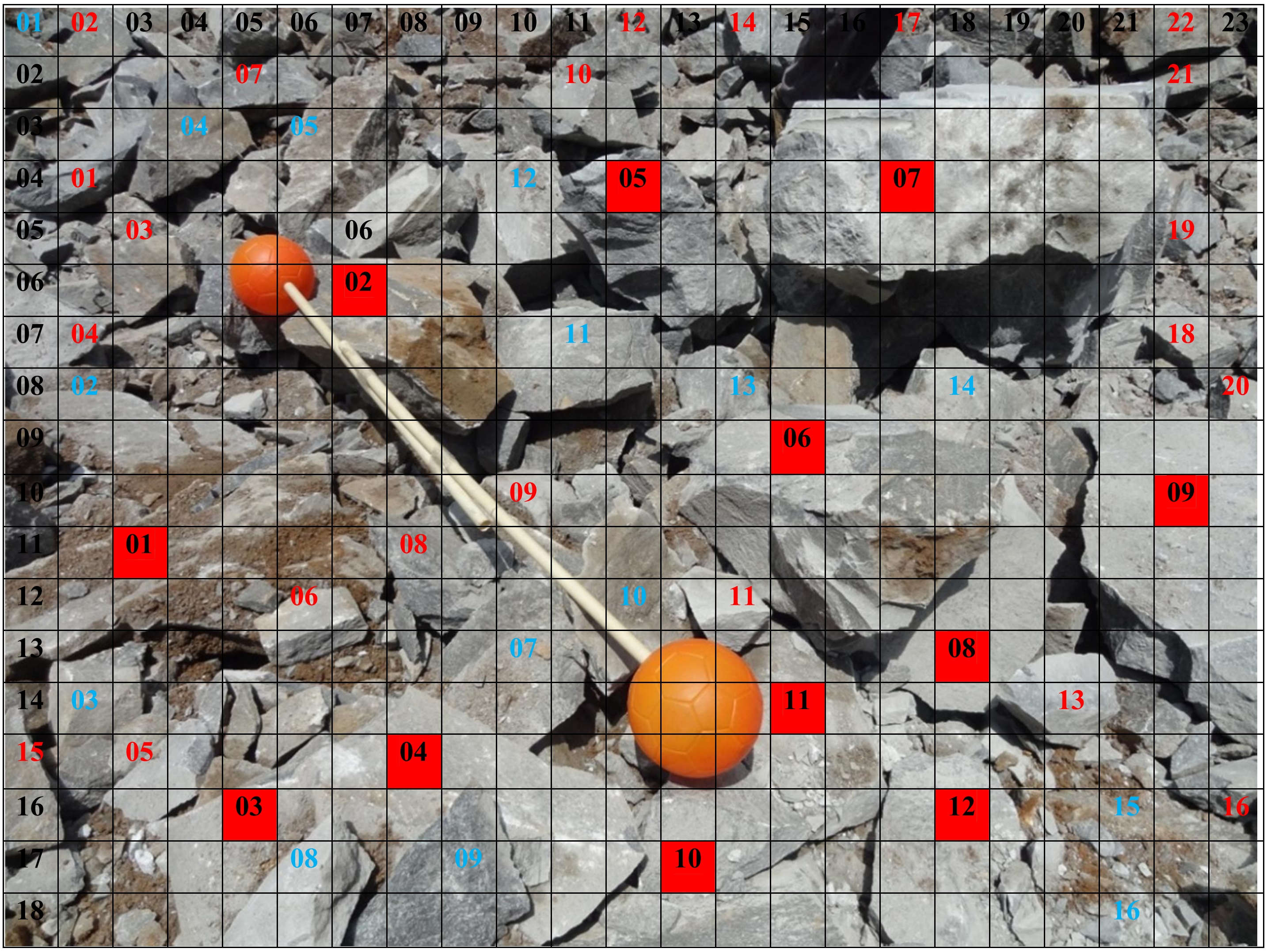

Figure-17.2.1: Location - 02, Blast -02-Fragmentation Analysis (Scale : Ball diameter is 20.32 cm)

Table- 10.2: Fragmentation Analysis of location - 02, blast – 02 of *Figure-17.2.1*

Size of fragments (Inches)	Numbers of fragments	Average
1-6	206	80.469 %
6-9 (Red colour)	**22**	8.594%
9-15 (Blue colour)	**16**	6.250 %
15< Boulders (Red Bold)	12	4.687%
Total	256	

Figure-17.3 : location - 02, Blast -03- (Scale: Ball diameter is 20.32 cm)

Figure-17.3.1: Location - 02, Blast -03-Fragmentation Analysis (Scale : Ball diameter is 20.32 cm)

Table- 10.3: Fragmentation Analysis of location - 02, blast – 03 of *Figure-17.3.1*

Size of fragments (Inches)	Numbers of fragments	Average
1-6	102	57.954%
6-9 (Red colour)	33	18.75 %
9-15 (Blue colour)	23	13.068%
15< Boulders (Red Bold)	18	10.227%
Total	176	

Figure-17.4 :location - 02, Blast -04- (Scale: Ball diameter is 20.32 cm)

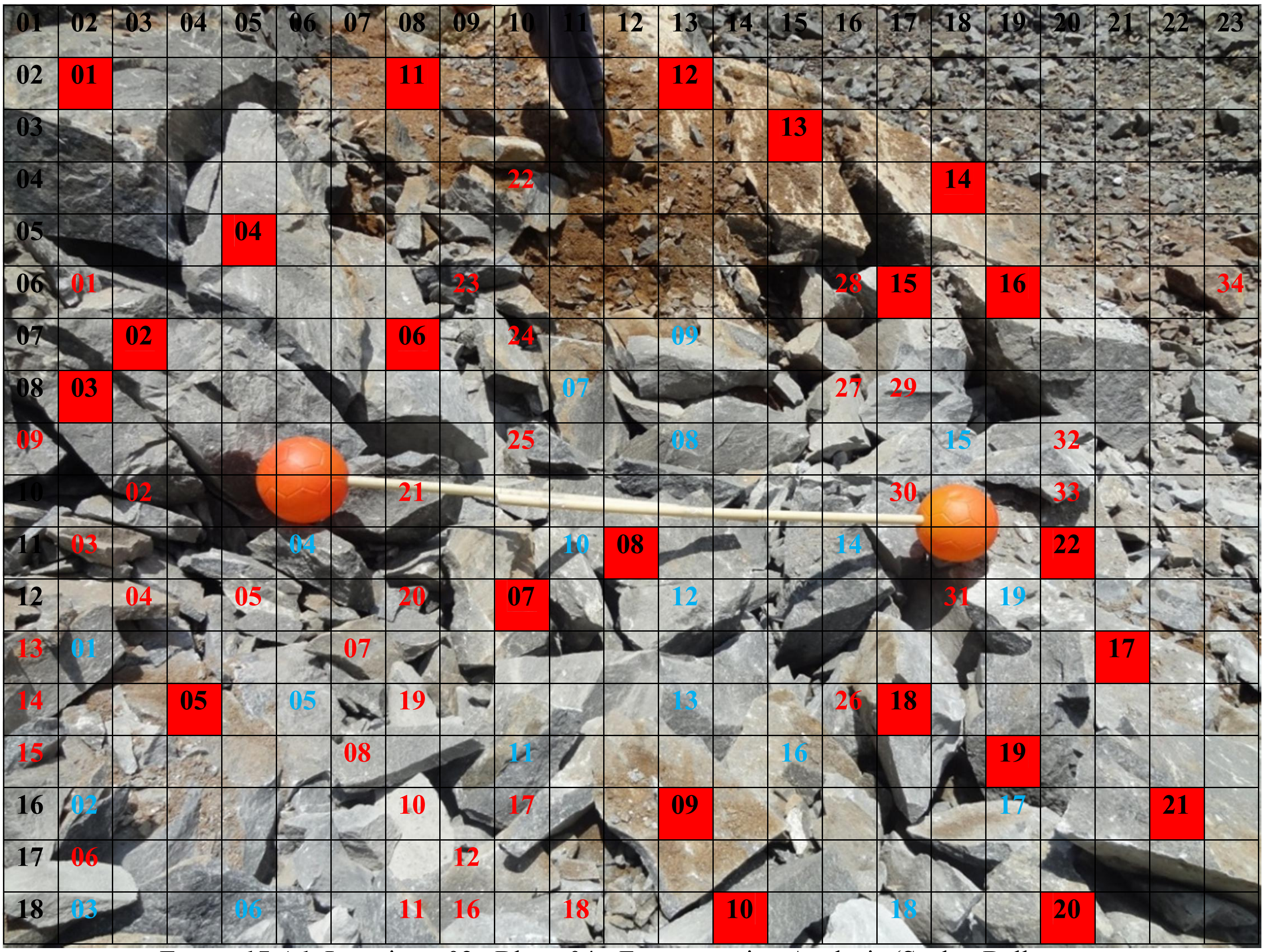

Figure-17.4.1: Location - 02, Blast -04 -Fragmentation Analysis (Scale : Ball diameter is 20.32 cm)

Table- 10.4: Fragmentation Analysis of location - 02, blast – 04 of *Figure-17.4.1*

Size of fragments (Inches)	Numbers of fragments	Average
1-6	368	83.069%
6-9 (Red colour)	**34**	7.675%
9-15 (Blue colour)	**19**	4.289%
15< Boulders (Red Bold)	22	4.966%
Total	443	

Figure-17.5 :location - 02, Blast -05- (Scale: Ball diameter is 20.32 cm)

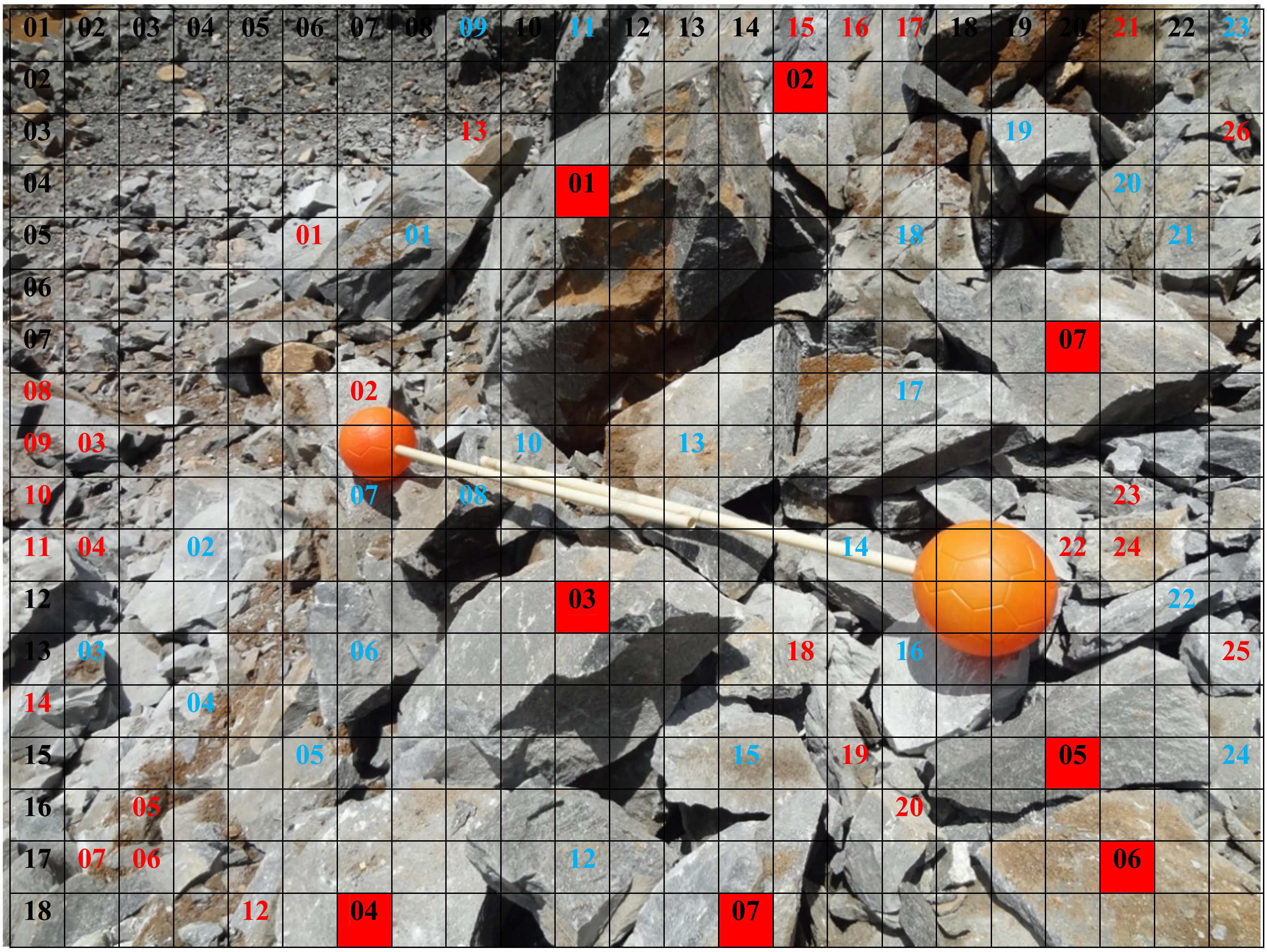

Figure-17.5.1: Location - 02, Blast -05 -Fragmentation Analysis (Scale : Ball diameter is 20.32 cm)

Table- 10.5: Fragmentation Analysis of location - 02, blast – 05 of *Figure-17.5.1*

Size of fragments (Inches)	Numbers of fragments	Average
1-6	290	83.574%
6-9 (Red colour)	**26**	7.492%
9-15 (Blue colour)	**24**	6.916 %
15< Boulders (Red Bold)	07	2.017%
Total	347	

Figure-17.6 :location - 02, Blast -06- (Scale: Ball diameter is 20.32 cm)

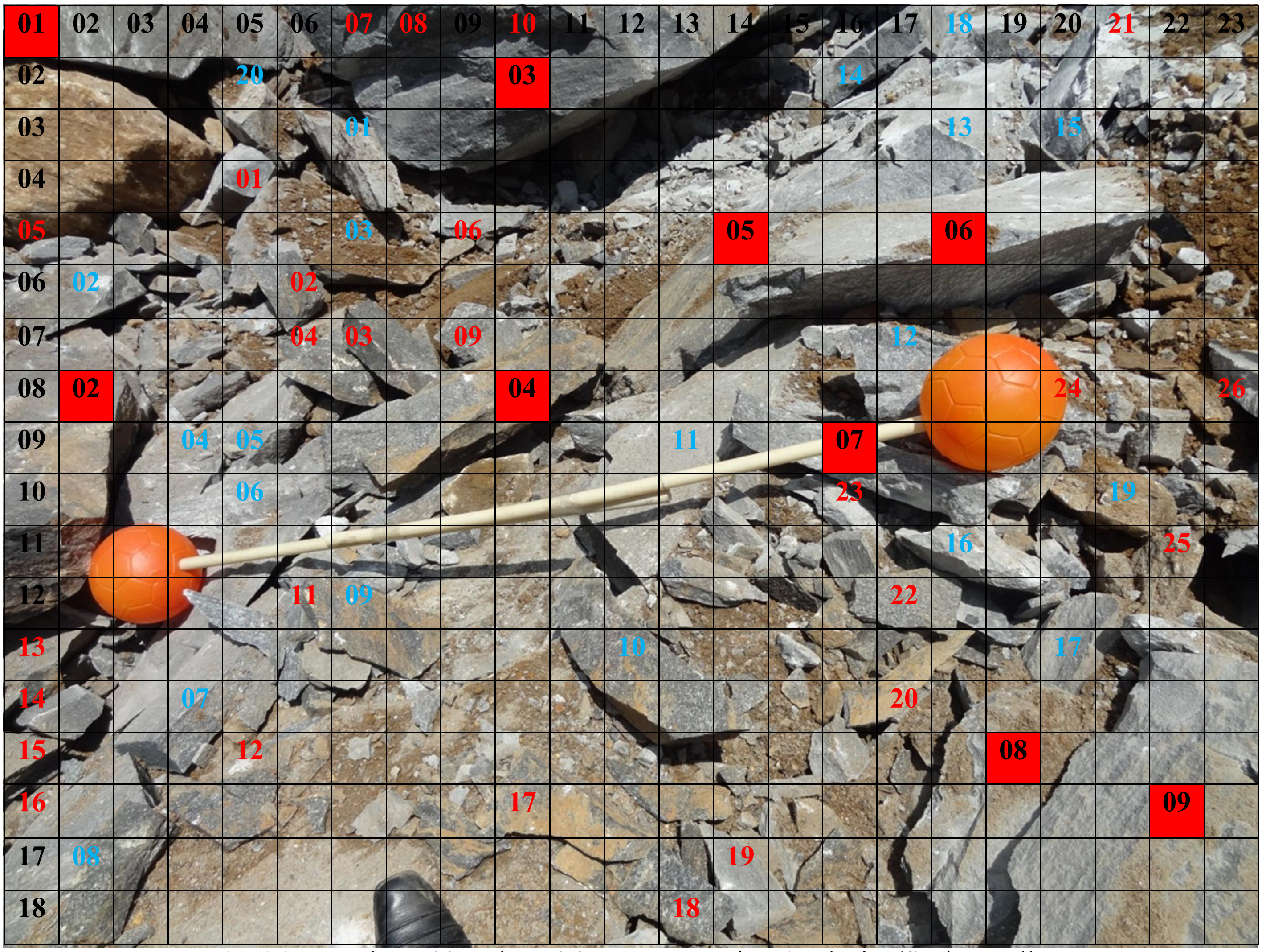

Figure-17.6.1: Location - 02, Blast -06 -Fragmentation Analysis (Scale : Ball diameter is 20.32 cm)

Table- 10.6: Fragmentation Analysis of location - 02, blast – 06 of *Figure-17.6.1*

Size of fragments (Inches)	Numbers of fragments	Average
1-6	294	84.241%
6-9 (Red colour)	**26**	7.449%
9-15 (Blue colour)	**20**	5.731%
15< Boulders (Red Bold)	09	2.578%
Total	349	

Field application details are summarized as below Table-11, regarding the above location-02, six bore hole blasting.

4.2.3. Comparison of the blast location-02

Table-11 :The summary of Six boreholes blasting at location-02

Number of Borehole	01	02	03	04	05	06
Borehole diameter (mm)	38	38	38	38	38	38
Borehole depth (m)	1.524	1.524	1.524	1.524	1.524	1.524
Burden (m)	0.914	0.914	0.914	0.914	0.914	0.914
Emulsion (kg)	0.13	0.13	0.13	0.13	0.13	0.13
Plain Detonator (No.)	01	01	01	01	01	01
AN/FO (kg)	0.35	0.35	0.35	0.35	0.35	0.35
Stemming (m)	0.6096	0.6096	0.6096	0.6096	0.6096	0.6096
Explosive Column height (m)	0.914	0.914	0.914	0.914	0.914	0.914
Fly rock thrown distance-m	6	4	3	4	8	6
Fragment scattered area-m^2	4	6	4	4	6	6
Material quantity after blasting. (Cube)	2.5	4	3	3	3	2
Material quantity after blasting. (m^3)	7.08	11.33	8.49	8.49	8.49	5.66
Specific Charge (kg m^{-3})	0.11	0.07	0.091	0.091	0.091	0.14
Average blasted rock volume	8.27m^3 (2.92 Cubes)					
Average Specific Charge	0.093 kg m^{-3}					

Average blasted rock volume = 8.27m^3

Average solid rock volume = 8.27m^3 / 1.6

Average solid rock volume = 5.17 m^3

Average Specific Charge = 0.48kg / 5.17 m^3

= 0.93 kgm^{-3}

4.3. Selected quarry location-03

Quarry Address - .Deraniyagala

District - Kegalle

Divisional Secretariat - Dehiovita

Coordinates - 195006N, 149038E

Quarry site is situated at Deloluwa village and land is called Deloluwa watta. In order to reach the quarry, one has to turn to left from the Dehiovita, and proceed along the Deraniyagala road. Dehiovita, Deraniyagala junction is located 1 km away from Dehiovita town of Awissawella-Kegalle main road. After proceeding about 5.5 km distance along the Deraniyagala road, Deloluwa bridge is identified and go straight to 1km and then crossing another small bridge, and is just appeared a road to right into the quarry with a small ramp.

Figure-18: Sample rock, Banded charnockite (fine grain) rock. (Charnockite with occasional banding and 5% > garnet.)

4.3.1. Selection of rock surface and preparation for testing at location-03

Carefully selected the good systematic, uninterrupted, no weathered surface, without joints, fractures or cracks. Selected area has enough solid surface to blast. Clear to observe the blasting yield, thus remove all the muck files and clean the quarry, before doing the field application.

4.3.2. Field application details at location-03

To get the idea of fragments, that took the photograph of each blast with 20.32 cm ball (scale) and then can calculate the separation of boulder size and count the number of boulders. The fly rock thrown distance of each blast is significant value and average value is 4.2 m of location no. 03. For details to see table-13. Absorption of blasting energy to rock, most probably is consumed to production and fragmentation of the rock. Detonation energy of Emulsion primer charge is highly adopted to the hardness of rock, therefore the production is the highest and input the maximum energy of primer charge to activate the rock breakage. *Figures from 18-1 to 18.6.1.*

Figure-18-1: Location - 03, Blast -01 - (Scale: Ball diameter is 20.32 cm)

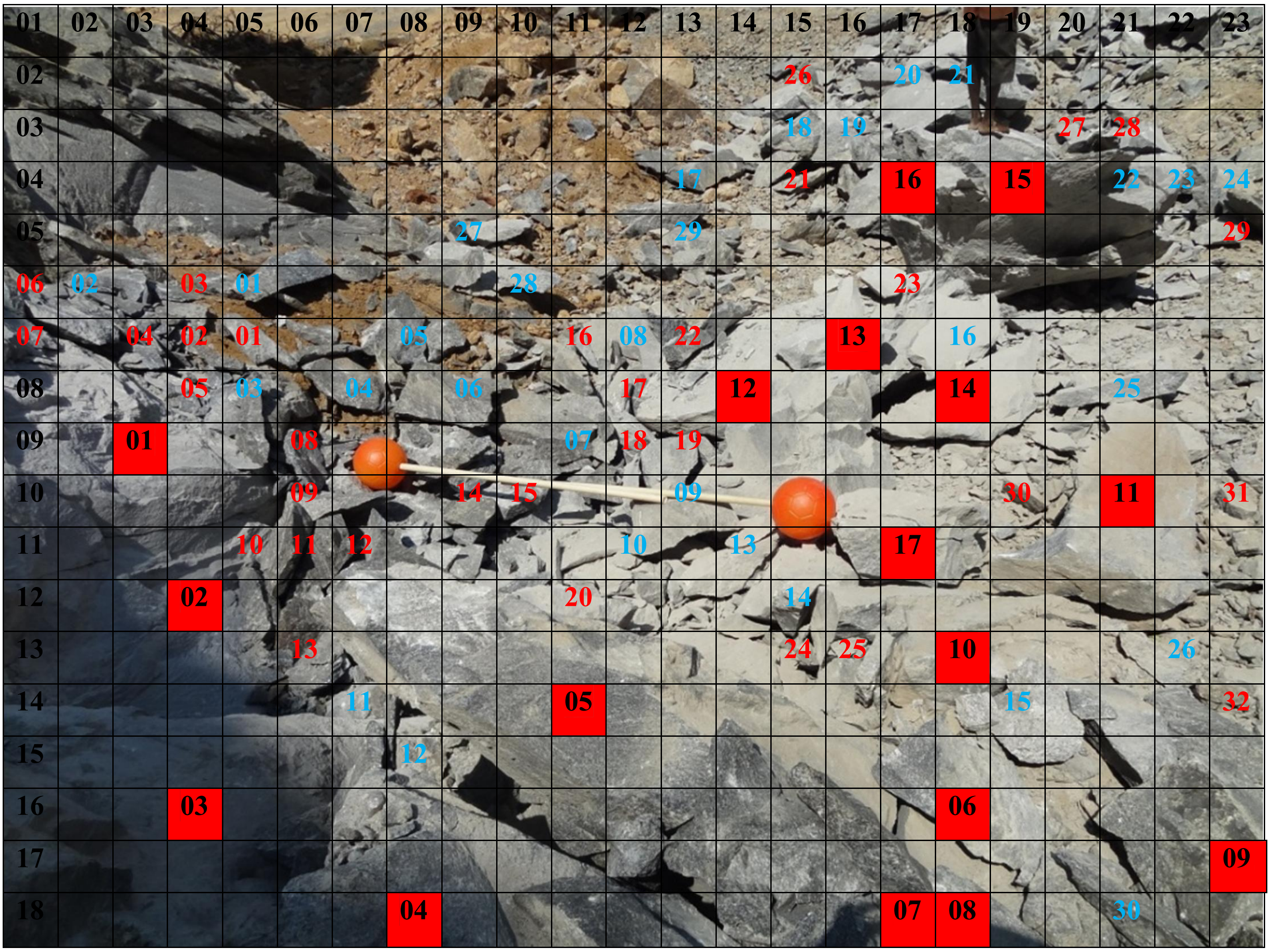

Figure-18.1.1: Location - 03, Blast -01 -Fragmentation Analysis
(Scale : Ball diameter is 20.32 cm)

Table- 12.1: Fragmentation Analysis of location - 03, blast – 01 of *Figure-18.1.1*

Size of fragments(Inches)	Numbers of fragments	Average
1-6	267	77.167%
6-9 (Red colour)	**32**	9.248%
9-15 (Blue colour)	**30**	8.670%
15< Boulders (Red Bold)	17	4.913%
Total	346	

Figure-18-2: Location - 03, Blast -02- (Scale: Ball diameter is 20.32 cm)

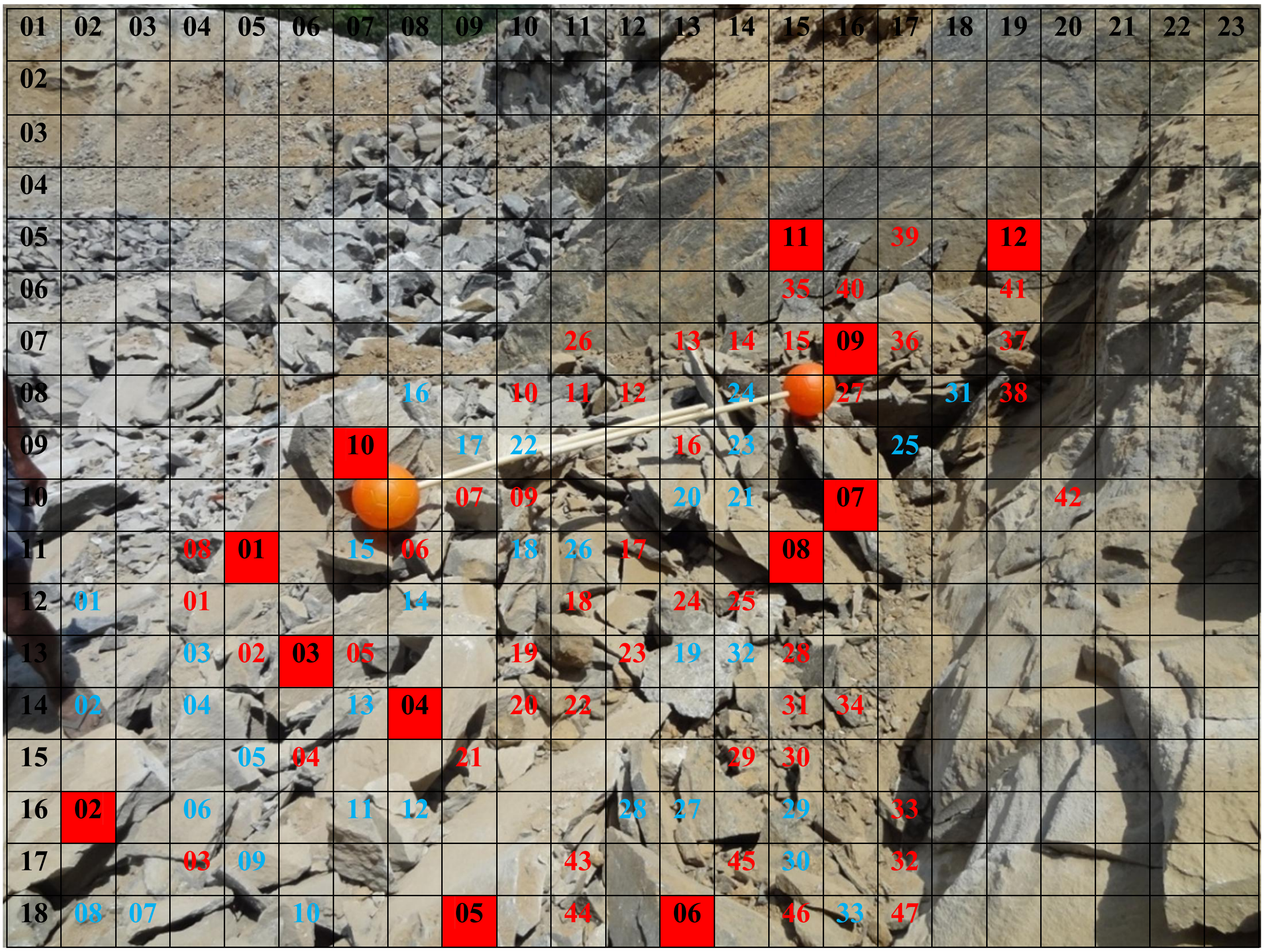

Figure-18-2.1: Location - 03, Blast -02 -Fragmentation Analysis (Scale : Ball diameter is 20.32 cm)

Table- 12.2: Fragmentation Analysis of location - 03, blast – 02 of *Figure-18.2.1*

Size of fragments(Inches)	Numbers of fragments	Average
1-6	222	70.701 %
6-9 (Red colour)	**47**	14.968%
9-15 (Blue colour)	**33**	10.509%
15< Boulders (Red Bold)	12	3.821 %
Total	314	

Figure-18-3 :location - 03, Blast -03- (Scale: Ball diameter is 20.32 cm)

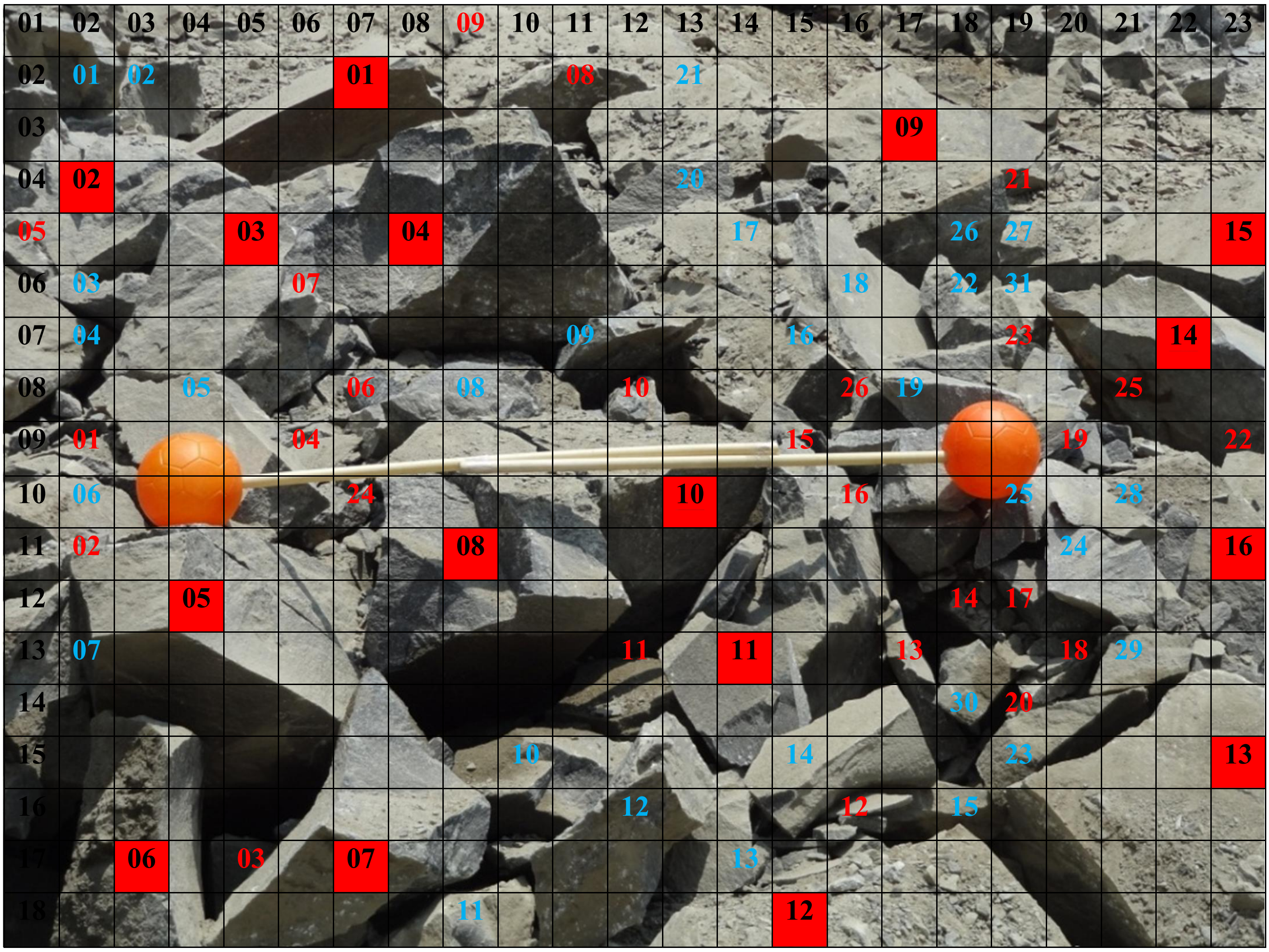

Figure-18-3.1: Location - 03, Blast -03 -Fragmentation Analysis
(Scale : Ball diameter is 20.32 cm)

Table- 12.3: Fragmentation Analysis of location - 03, blast – 03 of *Figure-18.3.1*

Size of fragments(Inches)	Numbers of fragments	Average
1-6	76	51.007%
6-9 (Red colour)	**26**	17.449%
9-15 (Blue colour)	**31**	20.805%
15< Boulders (Red Bold)	16	10.738%
Total	149	

Figure-18-4 : Location - 03, Blast -04 - (Scale: Ball diameter is 20.32 cm)

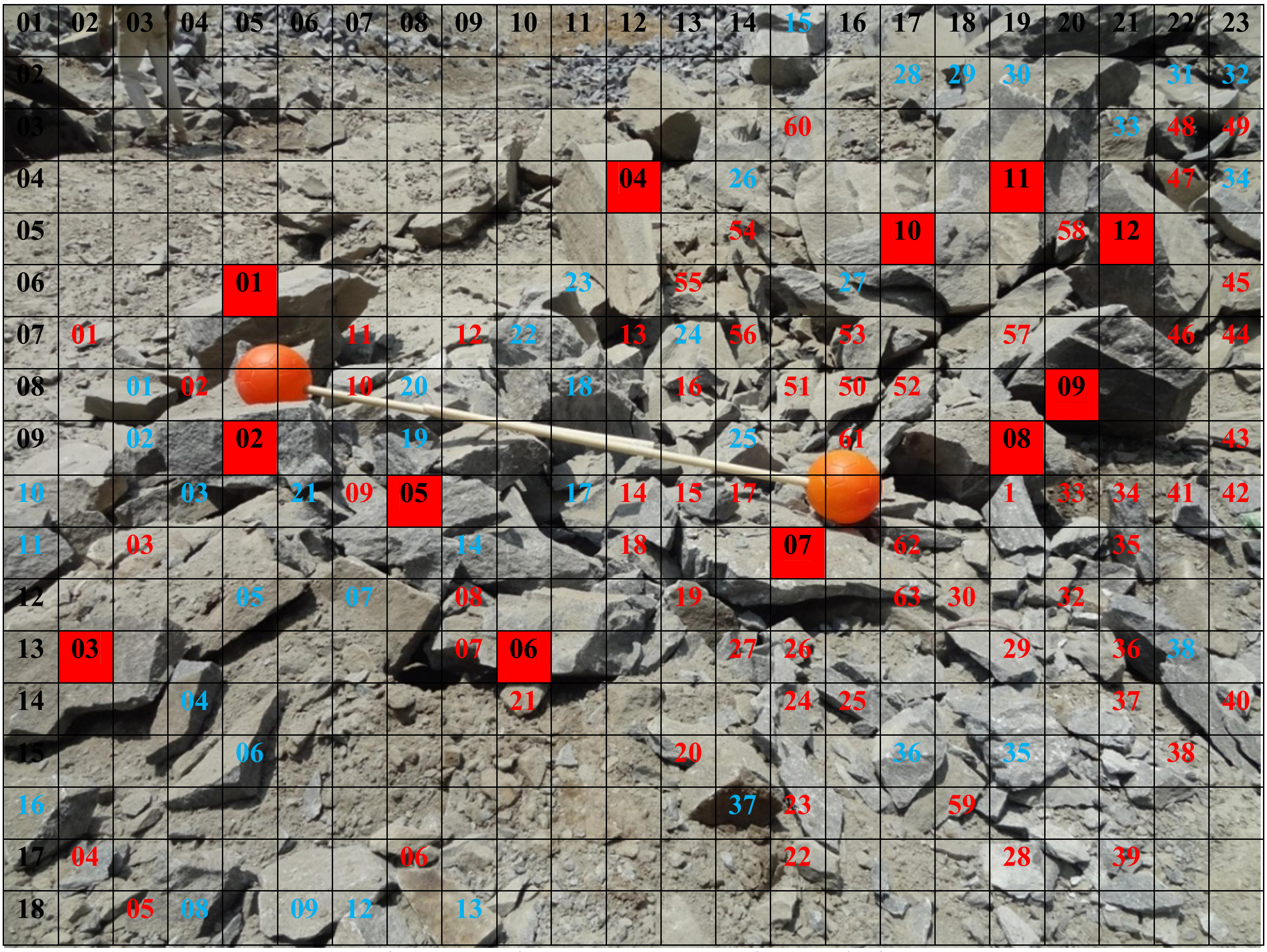

Figure-18-4.1: Location - 03, Blast -04 -Fragmentation Analysis
(Scale : Ball diameter is 20.32 cm)

Table- 12.4:Fragmentation Analysis of location - 03, blast – 04 of *Figure-18.4.1*

Size of fragments(Inches)	Numbers of fragments	Average
1-6	288	71.820%
6-9 (Red colour)	**63**	15.711%
9-15 (Blue colour)	**38**	9.476%
15< Boulders (Red Bold)	12	2.992%
Total	401	


Figure-18-5: Location - 03,   Blast -05- (Scale: Ball diameter is 20.32 cm)

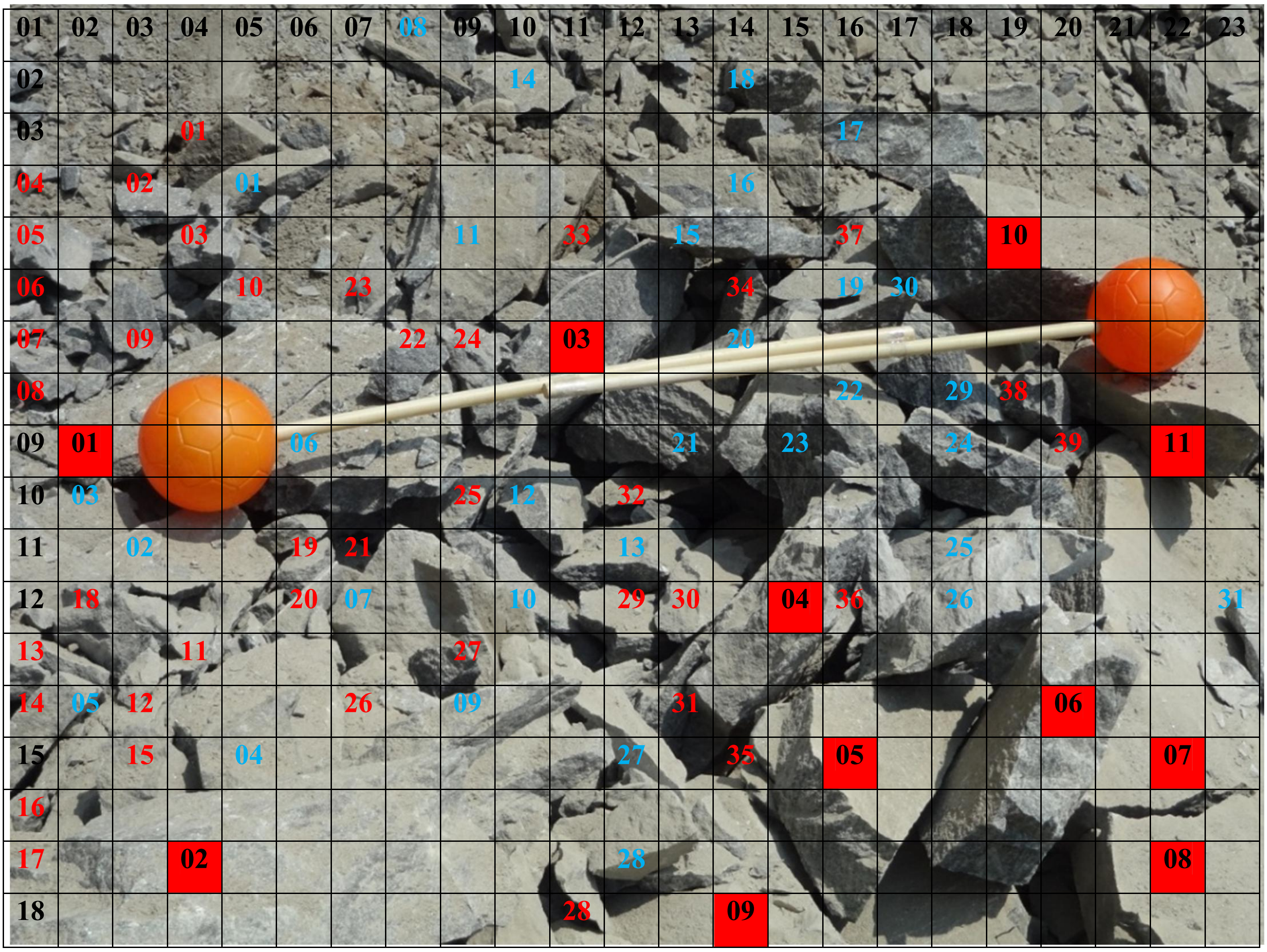

Figure-18-5.1: Location - 03, Blast -05 -Fragmentation Analysis (Scale : Ball diameter is 20.32 cm)

Table- 12.5: Fragmentation Analysis of location - 03, blast – 05 of *Figure-18.5.1*

Size of fragments(Inches)	Numbers of fragments	Average
1-6	128	61.244%
6-9 (Red colour)	**39**	18.660%
9-15 (Blue colour)	**31**	14.832%
15< Boulders (Red Bold)	11	5.263%
Total	209	

Figure-18-6 :location - 03, Blast -06- (Scale: Ball diameter is 20.32 cm)

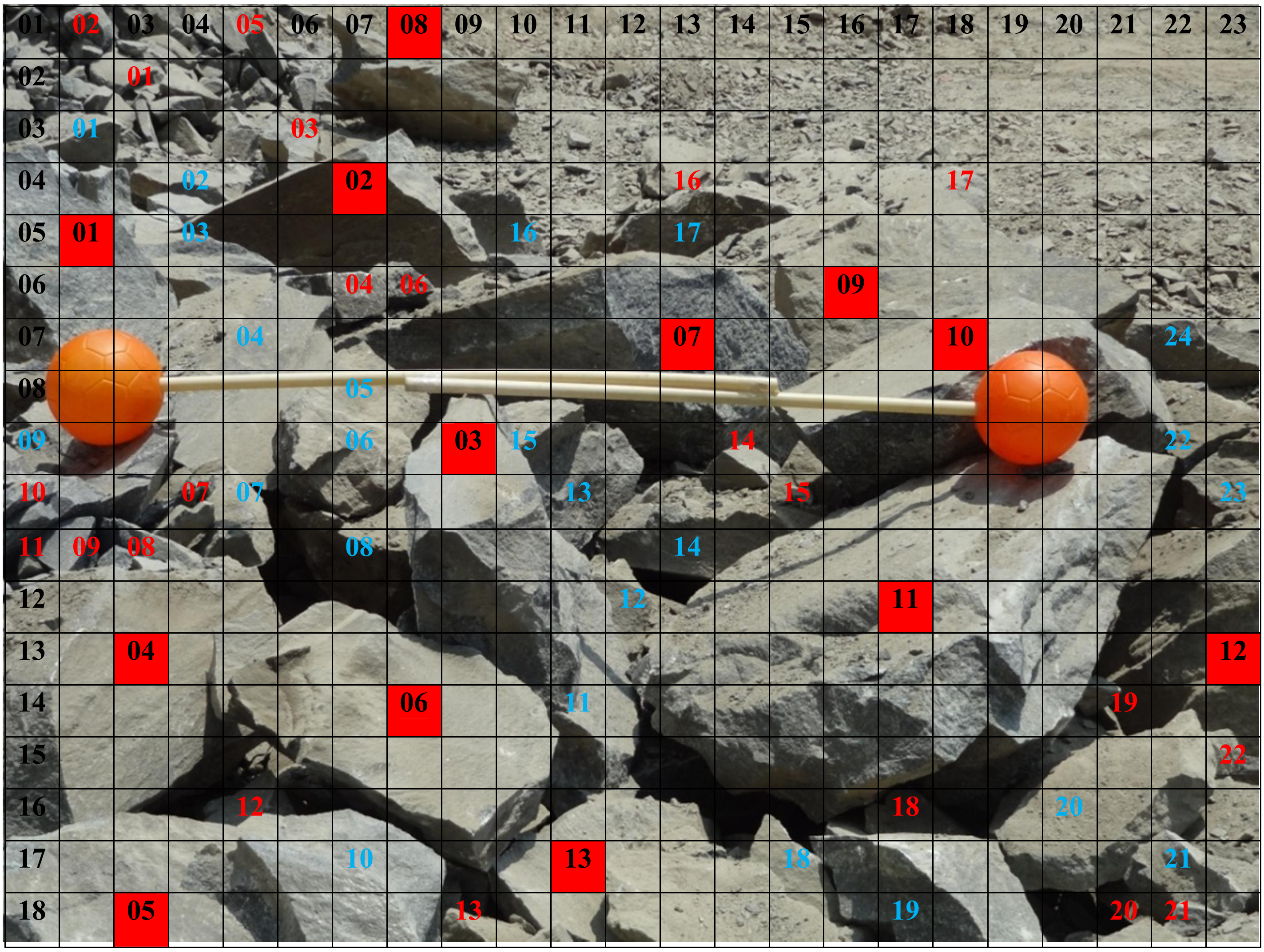

Figure-18-6.1: Location - 03, Blast -06 -Fragmentation Analysis (scale : Ball diameter is 20.32 cm)

Table- 12.6: Fragmentation Analysis of location - 03, blast – 06 of *Figure-18.6.1*

Size of fragments(Inches)	Numbers of fragments	Average
1-6	168	74.009%
6-9 (Red colour)	**22**	9.691%
9-15 (Blue colour)	**24**	10.572%
15< Boulders (Red Bold)	13	5.727%
Total	227	

Field application details are summarized as below Table-13, regarding the above location-03, six bore hole blasting.

4.3.3. Comparison of the blasted location-03

Table-13 :The summary of Six boreholes blasting at location-03

Number of Borehole	**01**	**02**	**03**	**04**	**05**	**06**
Borehole diameter (mm)	38	38	38	38	38	38
Borehole depth (m)	1.524	1.524	1.524	1.524	1.524	1.524
Burden (m)	0.914	0.914	0.914	0.914	0.914	0.914
Emulsion (kg)	0.13	0.13	0.13	0.13	0.13	0.13
Plain Detonator (No.)	01	01	01	01	01	01
AN/FO (kg)	0.35	0.35	0.35	0.35	0.35	0.35
Stemming (m)	0.6096	0.6096	0.6096	0.6096	0.6096	0.6096
Explosive Column height (m)	0.914	0.914	0.914	0.914	0.914	0.914
Fly rock thrown distance-m	6	2	3	6	4	4
Fragment scattered area-m^2	6	4	4	6	4	4
Material quantity after blasting. (Cube)	3	4	3	2	3	2
Material quantity after blasting. (m^3)	8.5	11.33	8.5	5.66	8.5	5.66
Specific Charge (kg m^{-3})	0.091	0.07	0.091	0.14	0.091	0.14
Average blasted rock volume	8.04 m^3 (2.84 Cubes)					
Average Specific Charge	0.096 kg m-3					

Average blasted rock volume = $8.04m^3$

Average solid rock volume = $8.04m^3 / 1.6$

Average solid rock volume = $5.025\ m^3$

Average Specific Charge = $0.48kg / 5.025\ m^3$

= $\underline{\underline{0.96\ kgm^{-3}}}$

4.4. Selected quarry location-04

Quarry Address - Kannathtota, Ruwanwella
District - Kegalle
Divisional Secretariat - Ruwanwella
Coordinates - 211125N, 142884E

Quarry site is situated at Kannathtota village and land is called Athalawa watta. In order to reach the quarry, one has to turn to right from the Kannathtota, and proceed along the Athalawa watta road. Athalawa watta junction is located half kilo meter before from Kannathtota small town of Kegalle-Awissawella main road. After proceeding about 2km distance along the Athalawa watta road, Pethangoda King Rajasinghe's sacred garden is located and go straight to 1km and then enter the quarry site.

Figure-19: Sample rock - Medium grain size charnockite rock with banded appearance.

4.4.1. Selection of rock surface and preparation for testing at location-04

Carefully selected the good systematic, uninterrupted, no weathered surface without joints, fractures or cracks. Selected area has enough solid surface to blast. Clear to observe the blasting yield, thus remove all the muck files and clean the quarry, before doing the field application.

4.4.2. Field Application Details at location-04

To get the idea of fragments, that took the photograph of each blast with 20.32 cm ball (scale) and then can calculate the separation of boulder size and count the number of boulders. The fly rock thrown distance of each blast is significant value and average value is 7.8m of location no.04. For details to see table-15. Absorption of blasting energy to rock, most probably is consumed to production and fragmentation of the rock. Detonation energy of Emulsion primer charge is highly adopted to the hardness of rock, therefore the production is the highest and input the maximum energy of primer charge to activate the rock breakage. See *Figures from 19.1 to 19.6.1.*

Figure-19.1 :location - 04, Blast -01 - (Scale: Ball diameter is 20.32 cm)

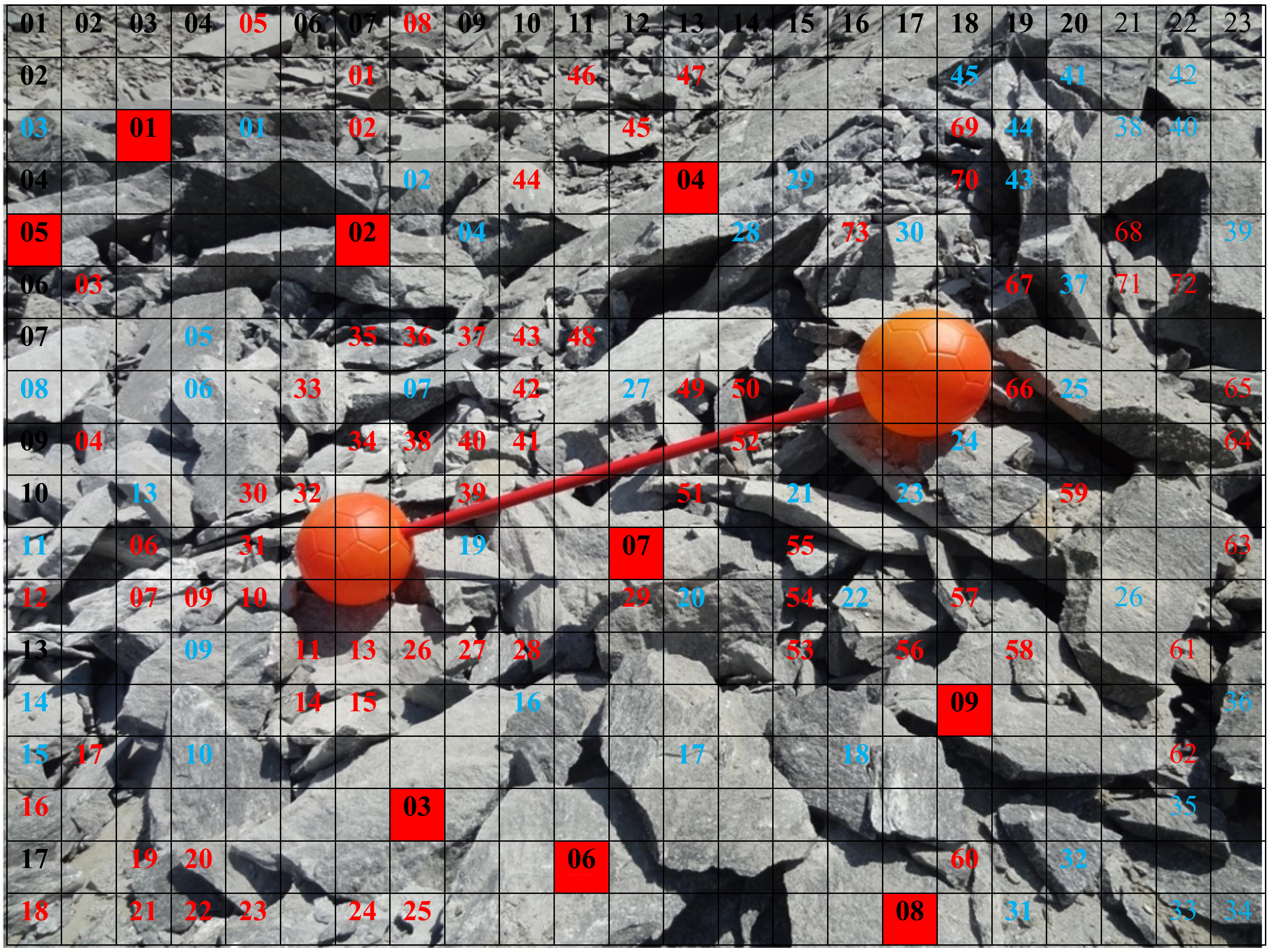

Figure-19-1.1: Location - 04, Blast -01-Fragmentation Analysis (Scale : Ball diameter is 20.32 cm)

Table- 14.1: Fragmentation Analysis of location - 04, blast – 01 of*Figure-19.1.1.*

Size of fragments (Inches)	Numbers of fragments	Average
1-6	412	76.438%
6-9 (Red colour)	**73**	13.543%
9-15 (Blue colour)	**45**	8.349%
15< Boulders (Red Bold)	09	1.669%
Total	539	

Figure-19.2: Location - 04,Blast -02- (Scale: Ball diameter is 20.32 cm)

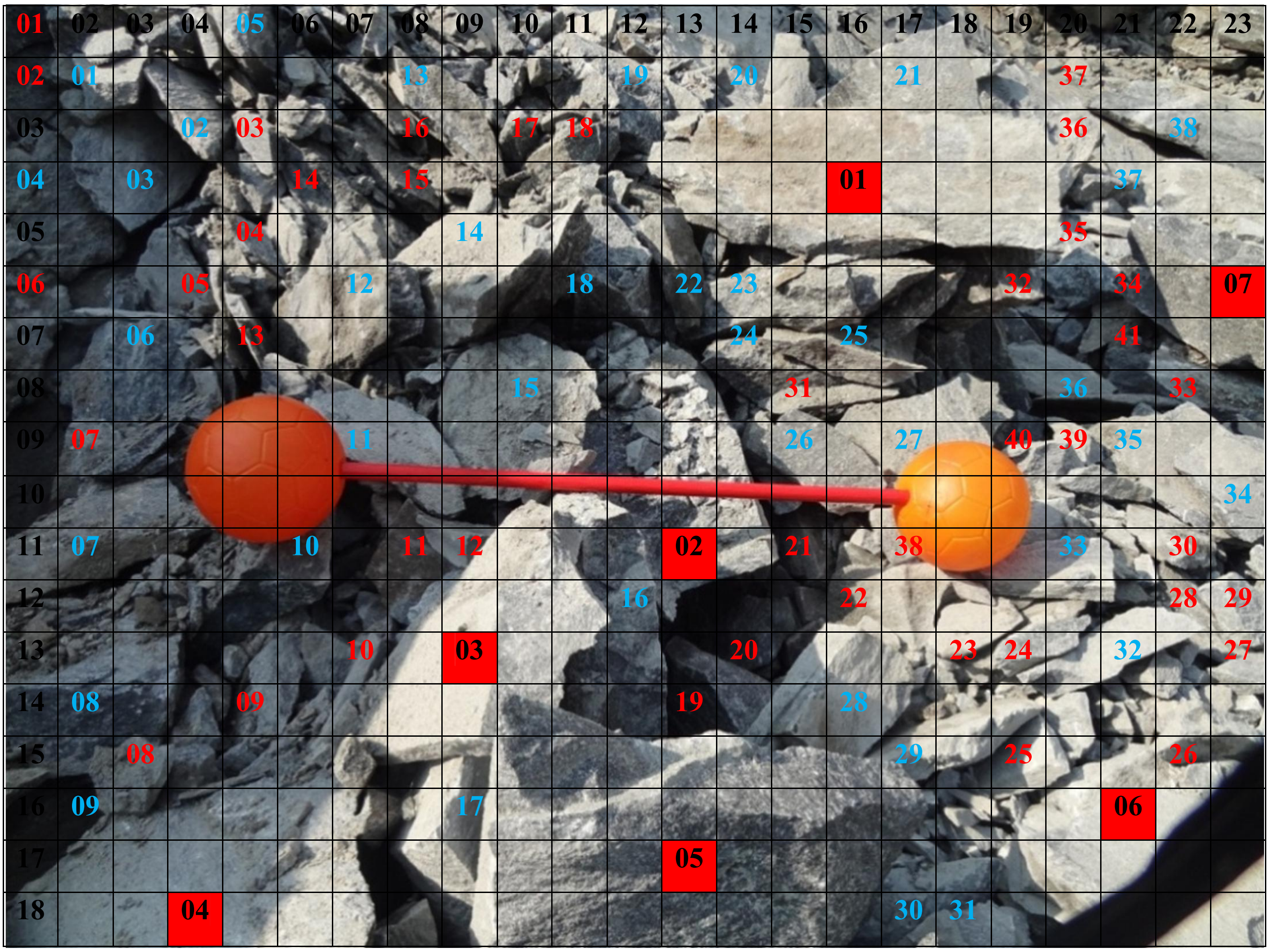

Figure-19.2.1: Location - 04, Blast -02 -Fragmentation Analysis
(Scale : Ball diameter is 20.32 cm)

Table- 14.2: Fragmentation Analysis of location - 04, blast – 02 of *Figure-19.2.1*

Size of fragments (Inches)	Numbers of fragments	Average
1-6	270	75.843%
6-9 (Red colour)	**41**	11.516%
9-15 (Blue colour)	**38**	10.674%
15< Boulders (Red Bold)	07	1.966%
Total	356	

Figure-19.3: Location - 04, Blast -03- (Scale: Ball diameter is 20.32 cm)

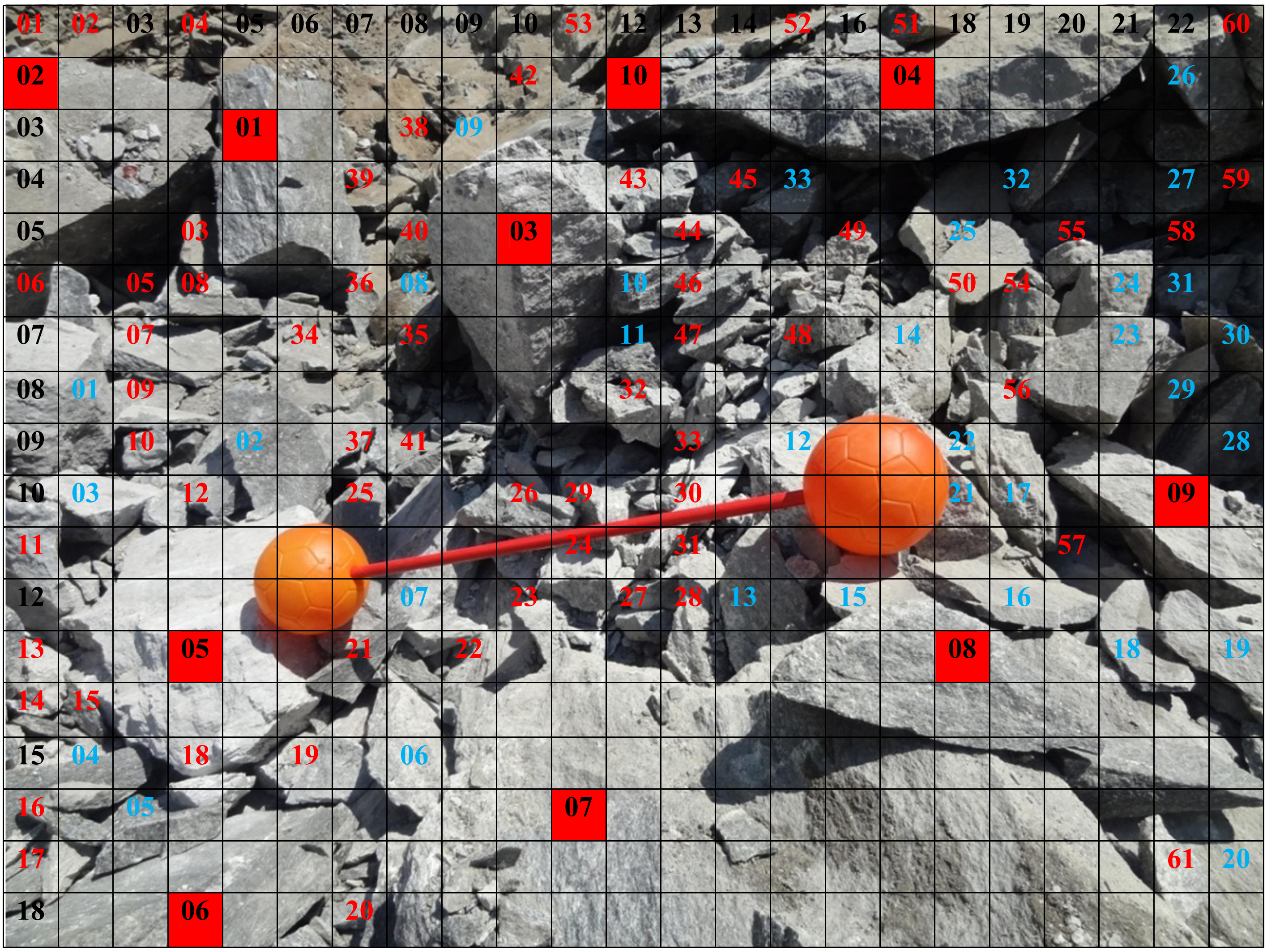

Figure-19-3.1: Location - 04, Blast -03 -Fragmentation Analysis
(Scale : Ball diameter is 20.32 cm)

Table- 14.3: Fragmentation Analysis of location - 04, blast – 03 of *Figure-19.3.1*

Size of fragments (Inches)	Numbers of fragments	Average
1-6	152	59.375%
6-9 (Red colour)	**61**	23.828%
9-15 (Blue colour)	**33**	12.891%
15< Boulders (Red Bold)	10	3.906 %
Total	256	

Figure-19-4: Location - 04, Blast -04- (Scale: Ball diameter is 20.32 cm)

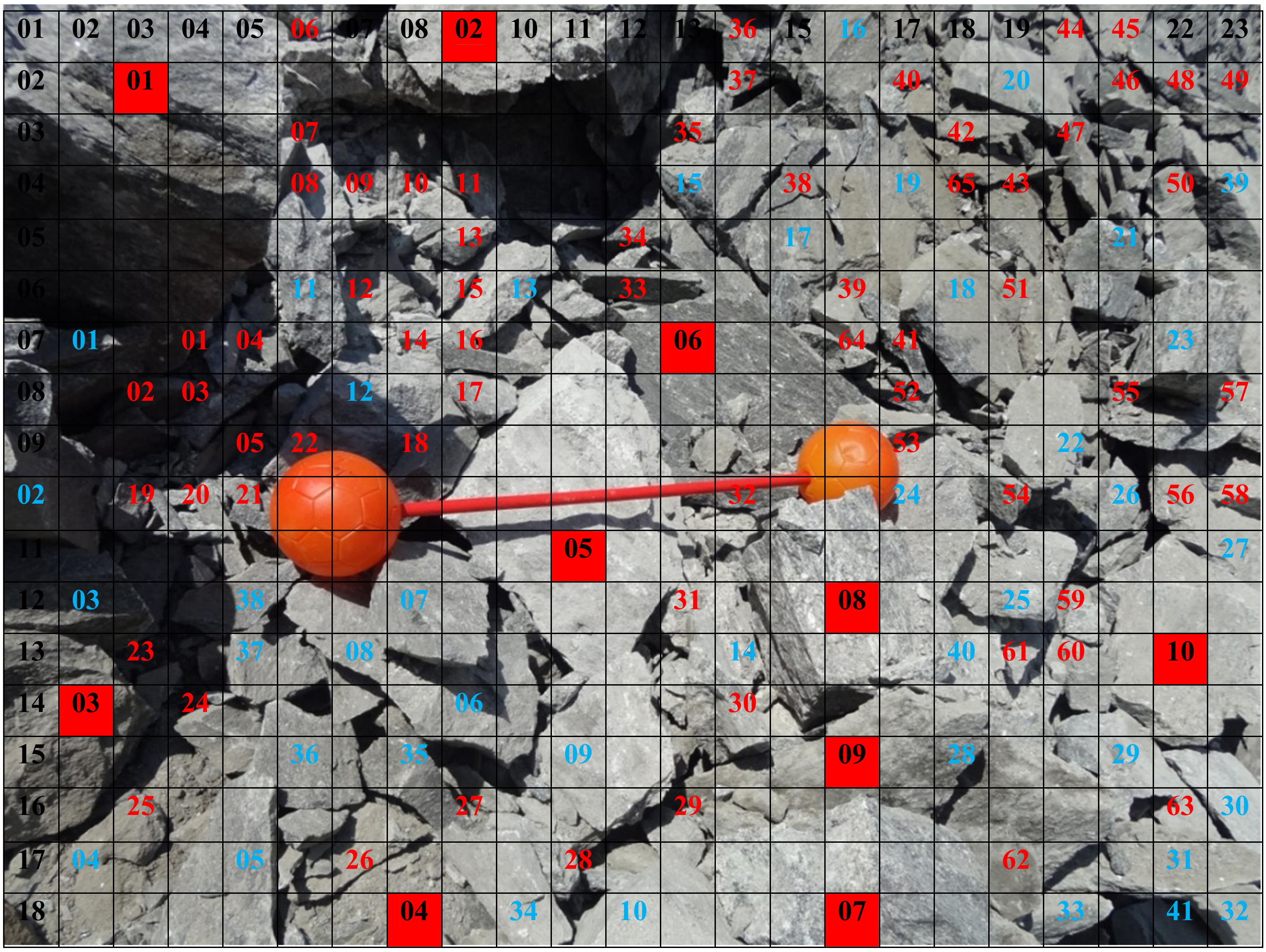

Figure-19-4.1: Location - 04, Blast -04 -Fragmentation Analysis
(Scale : Ball diameter is 20.32 cm)

Table- 14.4: Fragmentation Analysis of location - 04, blast – 04 of *Figure-19.4.1*

Size of fragments (Inches)	Numbers of fragments	Average
1-6	83	41.708%
6-9 (Red colour)	**65**	32.663%
9-15 (Blue colour)	**41**	20.603%
15< Boulders (Red Bold)	10	5.025%
Total	199	

Figure-19-5 :location - 04, Blast -05- (Scale: Ball diameter is 20.32 cm)

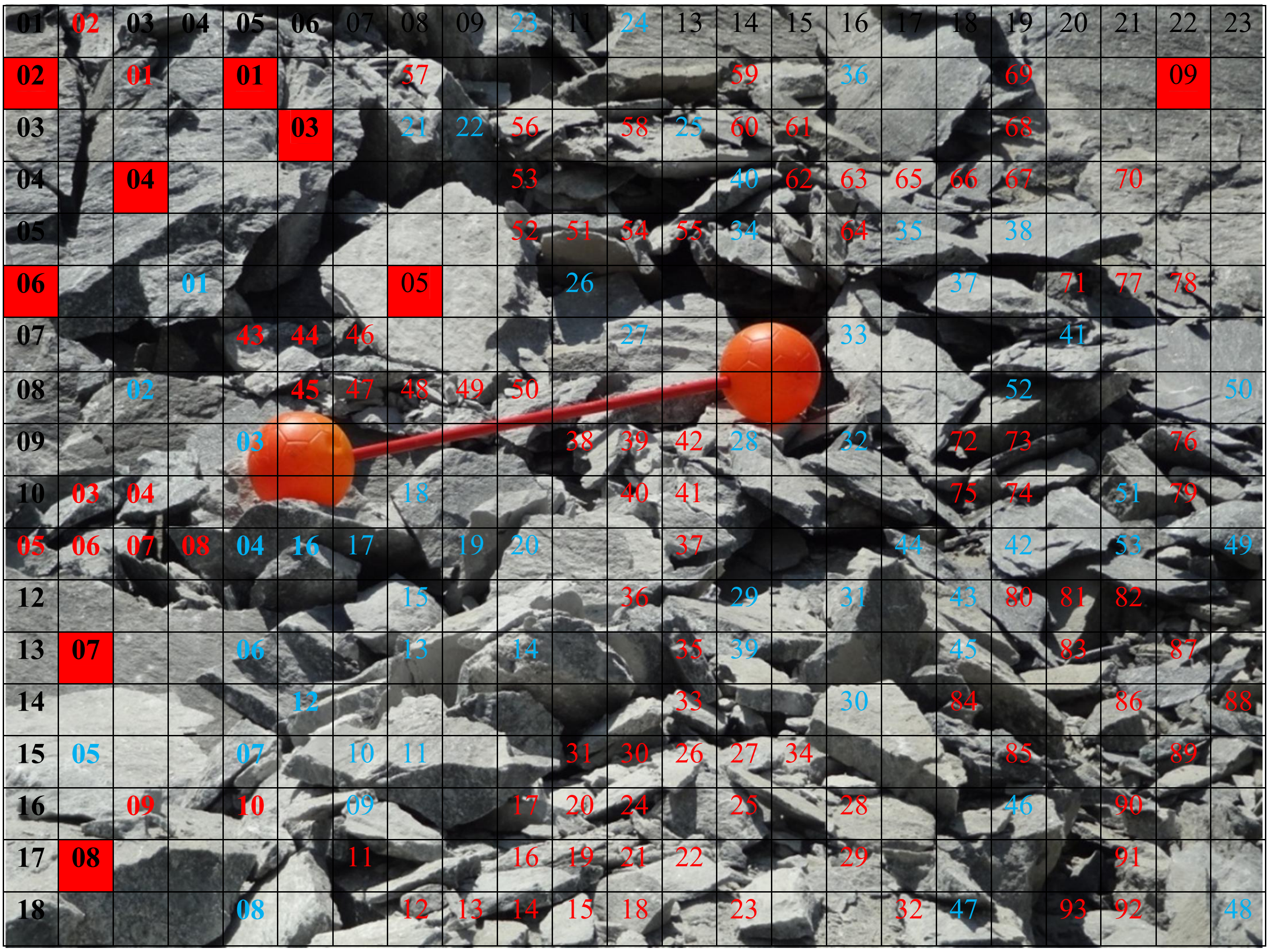

Figure-19-5.1: Location - 04, Blast -05 -Fragmentation Analysis (Scale : Ball diameter is 20.32 cm)

Table- 14.5: Fragmentation Analysis of location - 04, blast – 05 of *Figure-19.5.1*

Size of fragments (Inches)	Numbers of fragments	Average
1-6	144	48.160%
6-9 (Red colour)	**93**	31.104%
9-15 (Blue colour)	**53**	17.725%
15< Boulders (Red Bold)	09	3.010%
Total	299	

Figure-19-6 : Location - 04, Blast -06- (Scale: Ball diameter is 20.32 cm)

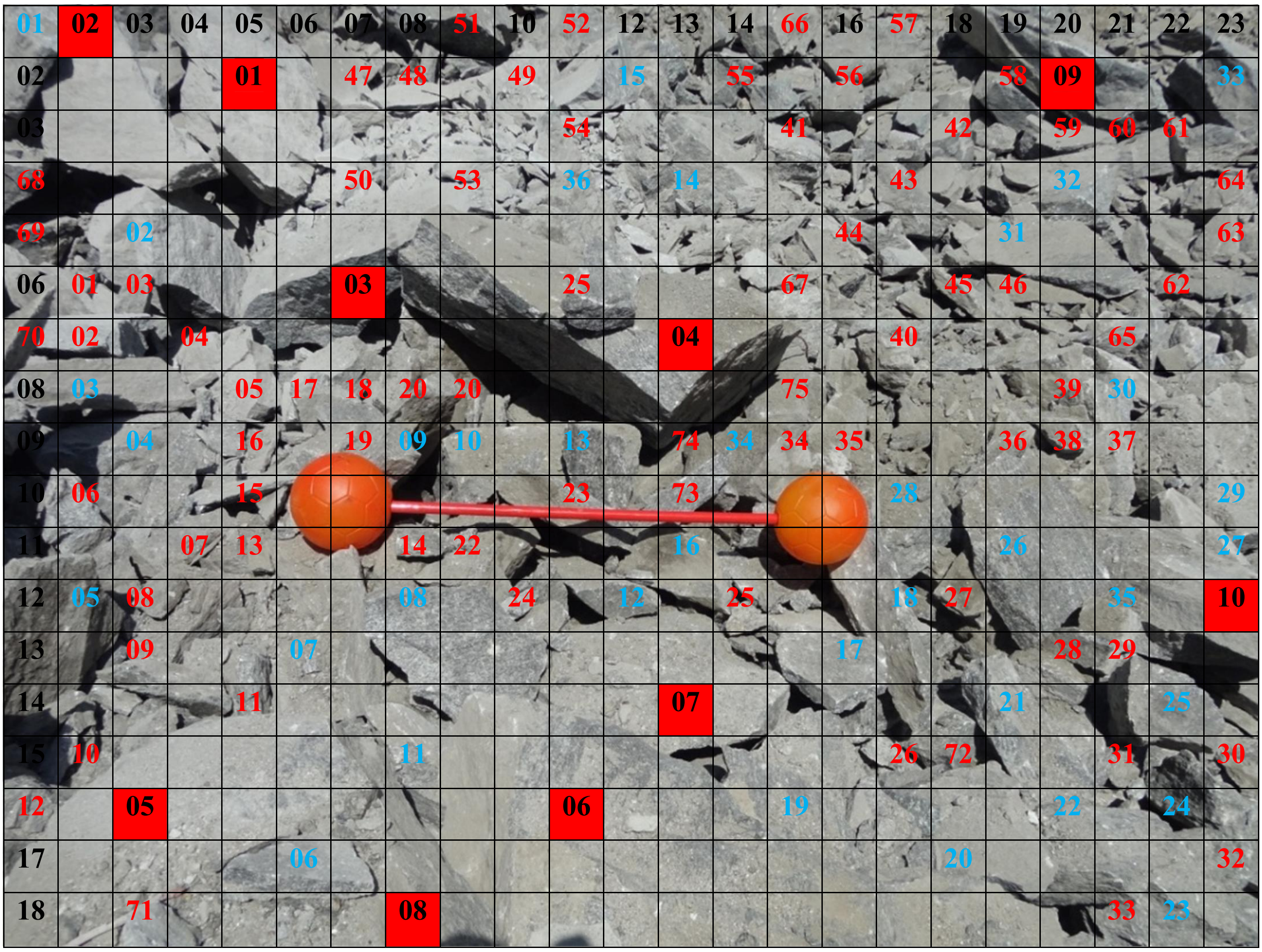

Figure-19-6.1: Location - 04, Blast -06 -Fragmentation Analysis (Scale : Ball diameter is 20.32 cm)

Table- 14.6: Fragmentation Analysis of location - 04, blast – 06 of *Figure-19.6.1*

Size of fragments (Inches)	Numbers of fragments	Average
1-6	298	71.291%
6-9 (Red colour)	**75**	17.942%
9-15 (Blue colour)	**35**	8.373%
15< Boulders (Red Bold)	10	2.392%
Total	418	

Field application details are summarized as below Table-15, regarding the above location-04, six bore hole blasting.

4.4.3. Comparison of the blasted location-04

Table-15: The summary of Six boreholes blasting at location-04

Number of Borehole	**01**	**02**	**03**	**04**	**05**	**06**
Borehole diameter (mm)	38	38	38	38	38	38
Borehole depth (m)	1.524	1.524	1.524	1.524	1.524	1.524
Burden (m)	0.914	0.914	0.914	0.914	0.914	0.914
Emulsion (kg)	0.13	0.13	0.13	0.13	0.13	0.13
Plain Detonator (No.)	01	01	01	01	01	01
AN/FO (kg)	0.35	0.35	0.35	0.35	0.35	0.35
Stemming (m)	0.6096	0.6096	0.6096	0.6096	0.6096	0.6096
Explosive Column height (m)	0.914	0.914	0.914	0.914	0.914	0.914
Fly rock thrown distance-m	10	5	6	9	8	9
Fragment scattered area-m^2	16	9	12	6	4	6
Material quantity after blasting. (Cube)	2	3	2.5	2	3	2.5
Material quantity after blasting. (m^3)	5.66	8.5	7.08	5.66	8.5	7.08
Specific Charge (kg m^{-3})	0.14	0.091	0.11	0.14	0.091	0.11
Average blasted rock volume	7.08 m^3 (2.5 Cubes)					
Average Specific Charge	0.11 kg m^{-3}					

Average blasted rock volume = 7.08 m^3

Average solid rock volume = 7.08 m^3 / 1.6

Average solid rock volume = 4.425m^3

Average Specific Charge = 0.48kg / 4.425 m^3

= <u>0.11 kgm-3</u>

4.5. Selected quarry location-05

Quarry Address	-	Kotadeniyawa, Diwulapitiya
District	-	Gampaha
Divisional Secretariat	-	Diulapitiya
Coordinates	-	231075N, 124322E

Quarry site is situated at Diyagampola village in Kotadeniyawa. In order to reach the quarry, one has to turn to right from Diyagampola to village road, and proceed along the road to 1km and quarry site is located on the right. Diyagampola junction is located half kilo meter away from Kotadeniyawa town of Colombo-Jaela-Kurunegala main road.

Figure-20: Sample rock - Banded biotite gneiss rock with 5% > garnet. Foliations are not well developed.

4.5.1. Selection of rock surface and preparation for testing at location-05

Carefully selected the good systematic, uninterrupted, no weathered surface without joints, fractures or cracks. Selected area has enough solid surface to blast. Clear to observe the blasting yield, thus remove all the muck files and clean the quarry, before doing the field application.

4.5.2. Field Application Details at location-05

To get the idea of fragments, that took the photograph of each blast with 20.32 cm ball (scale) and then can calculate the separation of boulder size and count the number of boulders. The fly rock thrown distance of each blast is significant value and average value is 9.7m of location no.05. For details to see table-17. Absorption of blasting energy to rock, most probably is consumed to production and fragmentation of the rock. Detonation energy of Emulsion primer charge is highly adopted to the hardness of rock, therefore the production is the highest and input the maximum energy of primer charge to activate the rock breakage. See *Figures from 20.1 to 20.6.1.*

Figure-20-1: Location -05, Blast -01 - (Scale: Ball diameter is 20.32 cm)

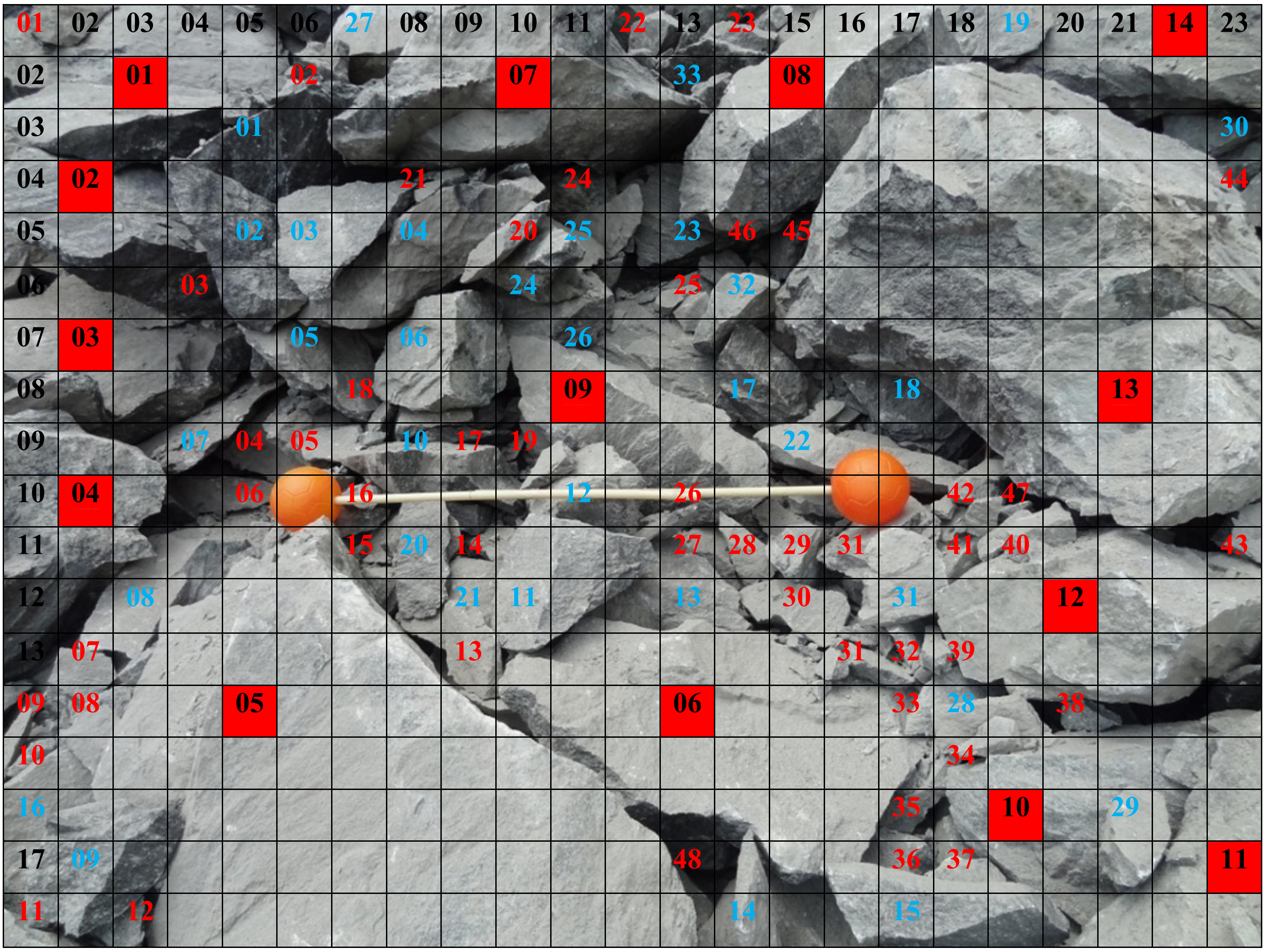

Figure-20.1.1: Location -05, Blast -01 -Fragmentation Analysis (Scale : Ball diameter is 20.32 cm)

Table- 16.1: Fragmentation Analysis of location -05, blast – 01 of *Figure-20.1.1*

Size of fragments (Inches)	Numbers of fragments	Average
1-6	81	46.023%
6-9 (Red colour)	**48**	27.272 %
9-15 (Blue colour)	**33**	18.75%
15< Boulders (Red Bold)	14	7.954%
Total	176	

Figure-20.2: Location -05, blast - 02, (Scale : Ball diameter is 20.32 cm)

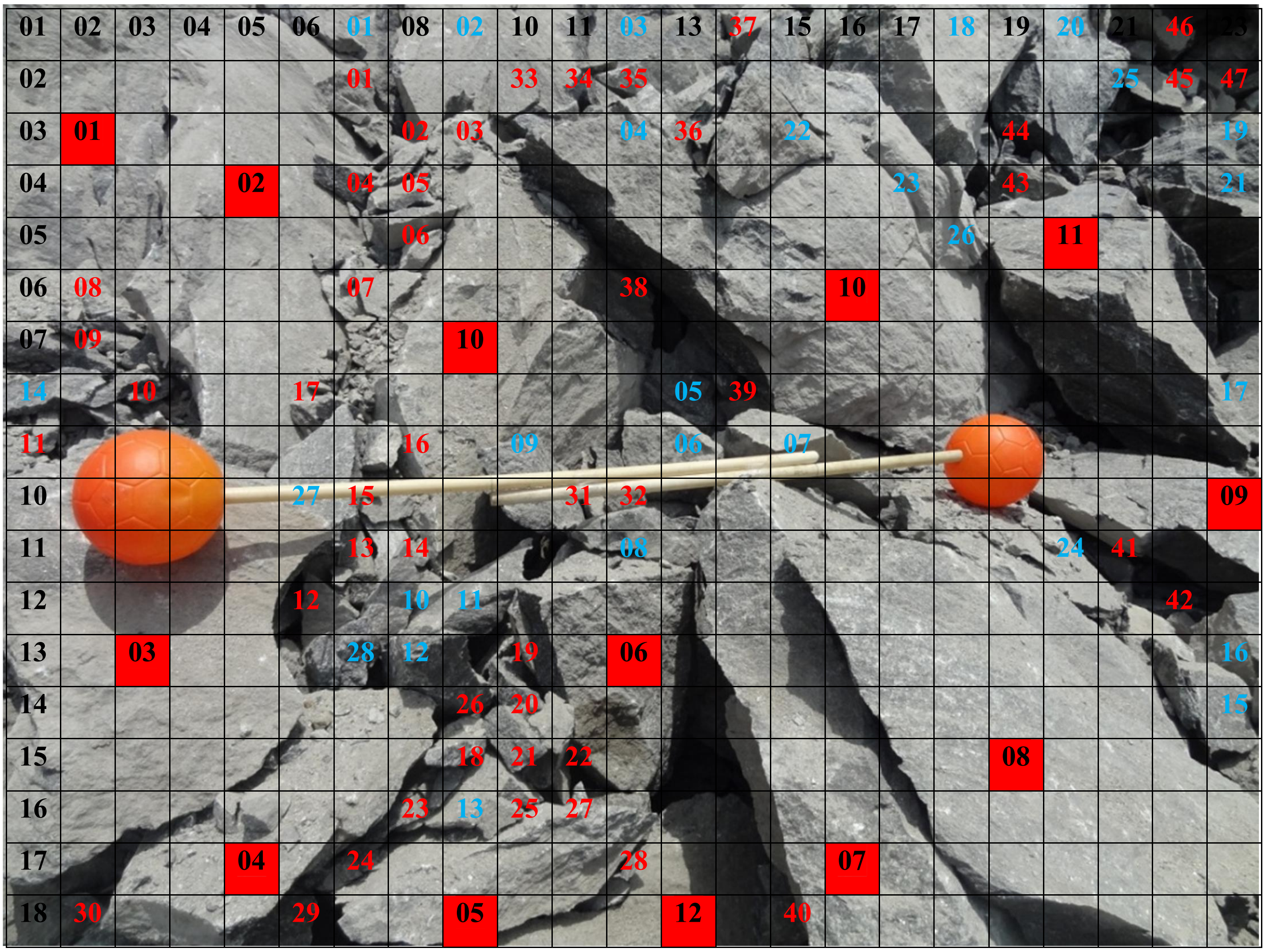

Figure-20.2.1: Location -05, Blast -02 -Fragmentation Analysis (Scale : Ball diameter is 20.32 cm)

Table- 16.2: Fragmentation Analysis of location -05, blast – 02 of *Figure-20.2.1*

Size of fragments (Inches)	Numbers of fragments	Average
1-6	114	56.716%
6-9 (Red colour)	**47**	23.383%
9-15 (Blue colour)	**28**	13.930%
15< Boulders (Red Bold)	12	5.970%
Total	201	

Figure-20.3: Location -05, blast - 03, (Scale : Ball diameter is 20.32 cm)

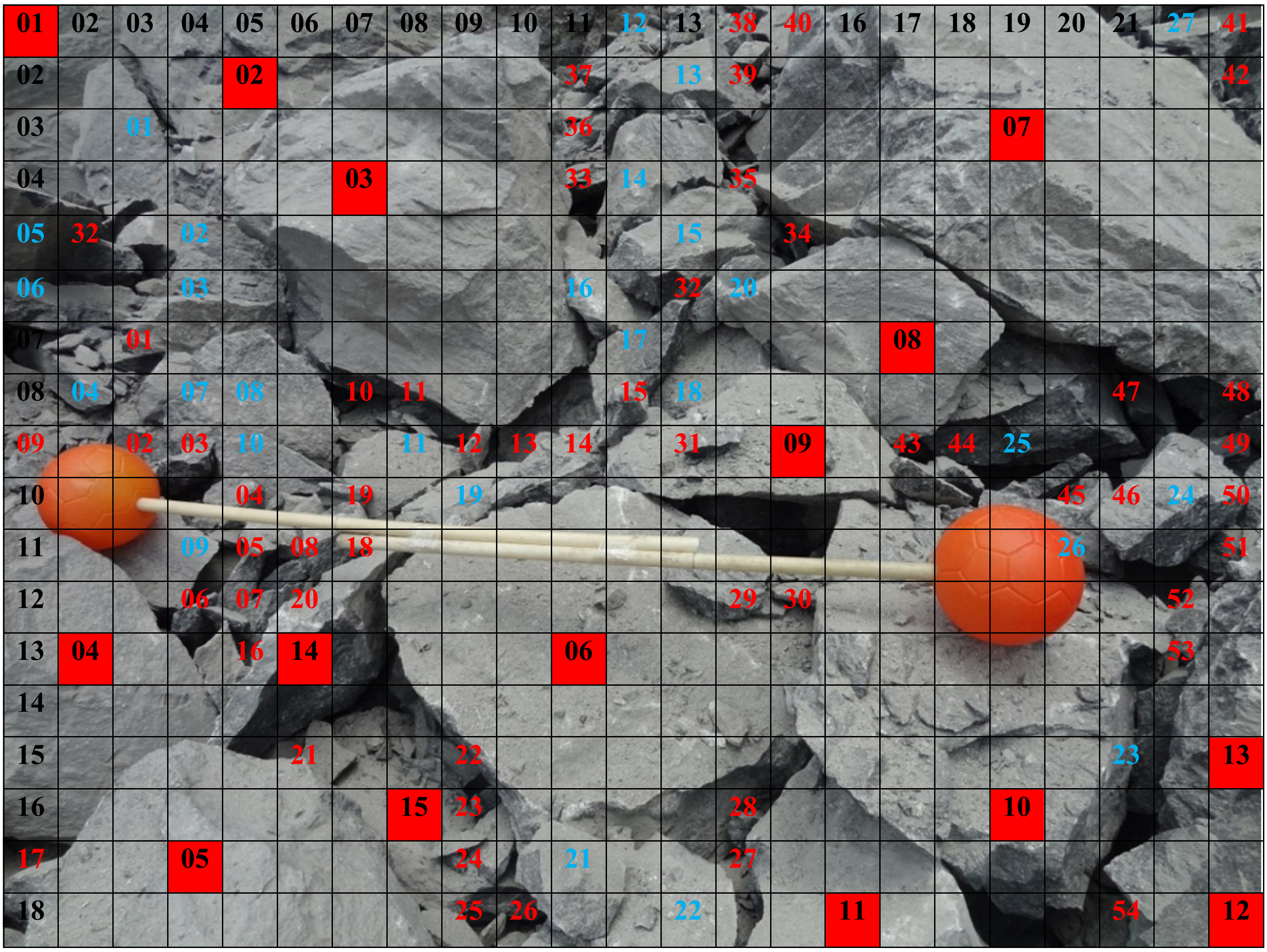

Figure-20-3.1: Location -05, Blast -03- Fragmentation Analysis (Scale: Ball diameter is 20.32 cm)

Table- 16.3: Fragmentation Analysis of location -05, blast – 03 of *Figure-20.3.1.*

Size of fragments (Inches)	Numbers of fragments	Average
1-6	106	52.475%
6-9 (Red colour)	**54**	26.733%
9-15 (Blue colour)	**27**	13.366 %
15< Boulders (Red Bold)	15	7.425%
Total	202	

Figure-20-4: Location -05, Blast -04- (Scale: Ball diameter is 20.32 cm)

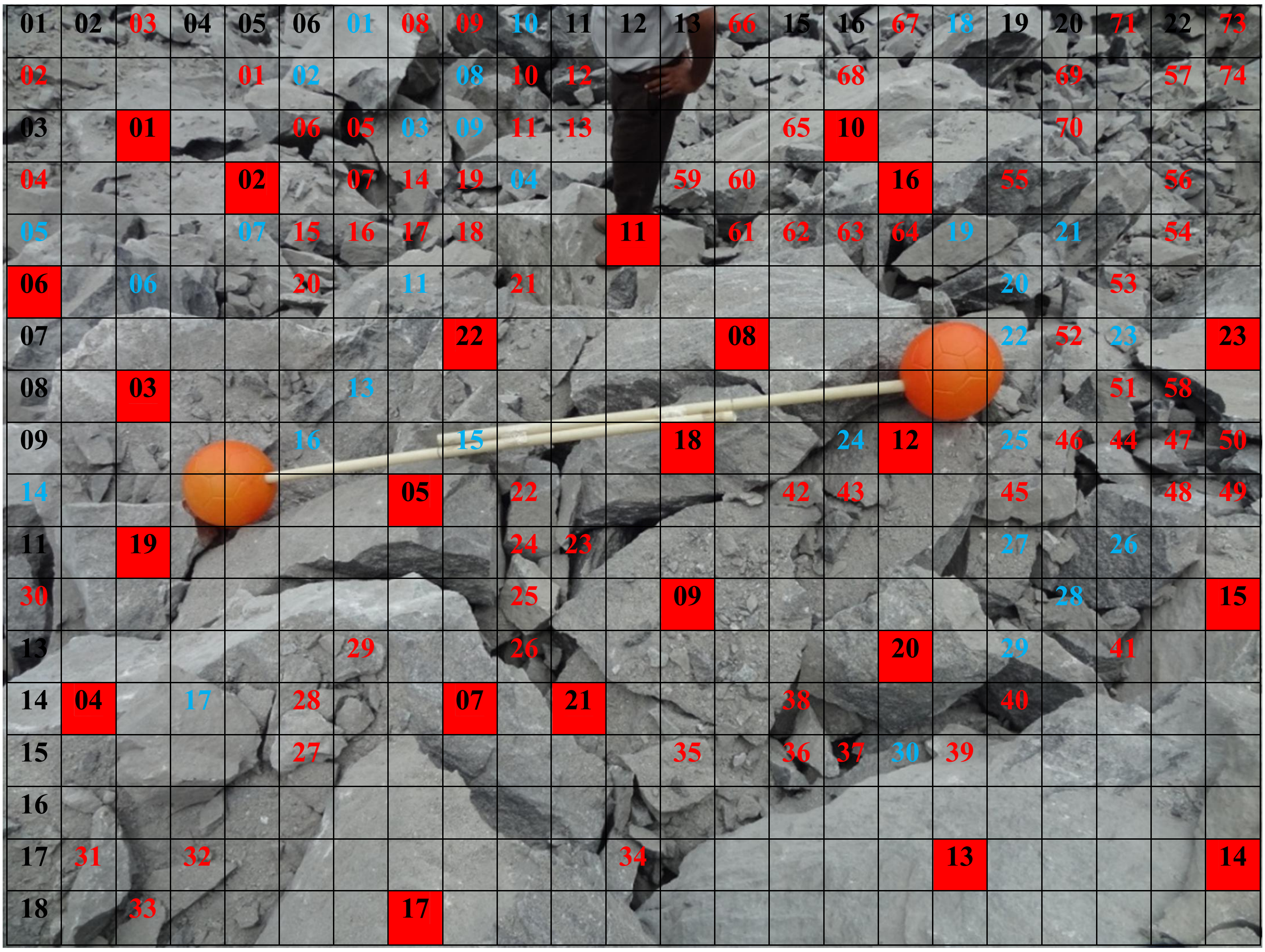

Figure-20-4.1: Location -05, Blast -04 -Fragmentation Analysis (Scale : Ball diameter is 20.32 cm)

Table- 16.4: Fragmentation Analysis of location -05, blast – 04 of *Figure-20.4.1*

Size of fragments (Inches)	Numbers of fragments	Average
1-6	237	65.110%
6-9 (Red colour)	**74**	20.329%
9-15 (Blue colour)	**30**	8.242%
15< Boulders (Red Bold)	23	6.318%
Total	364	

Figure-20-5: location -05, Blast -05- (Scale: Ball diameter is 20.32 cm)

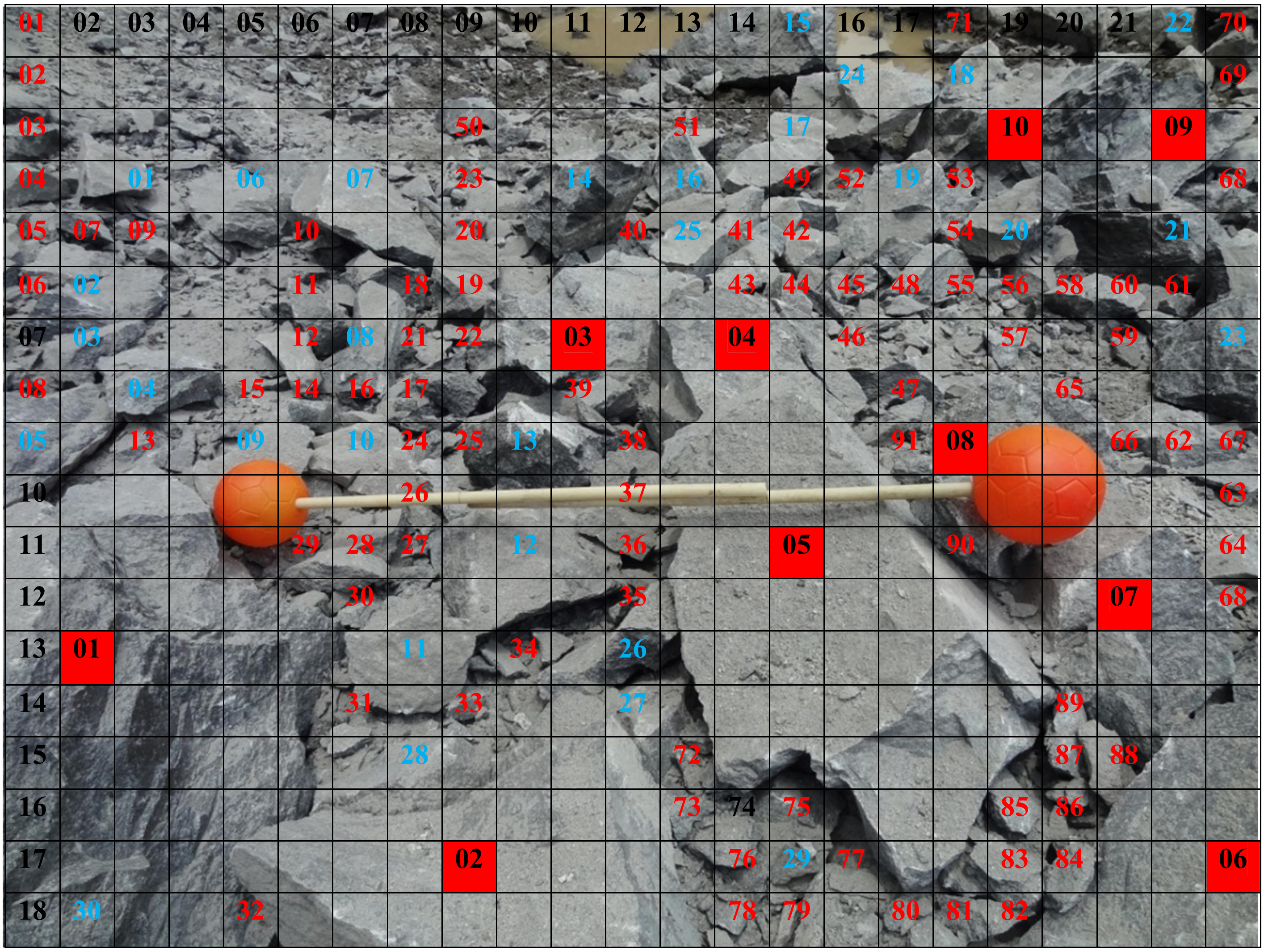

Figure-20-5.1: Location -05, Blast -05 - Fragmentation Analysis (Scale : Ball diameter is 20.32 cm)

Table- 16.5: Fragmentation Analysis of location -05, blast – 05 of *Figure-20.5.1*

Size of fragments (Inches)	Numbers of fragments	Average
1-6	411	75.830%
6-9 (Red colour)	**91**	16.790%
9-15 (Blue colour)	**30**	5.535%
15< Boulders (Red Bold)	10	1.845%
Total	542	


Figure-20.6: Location -05, Blast -06- (Scale: Ball diameter is 20.32 cm)

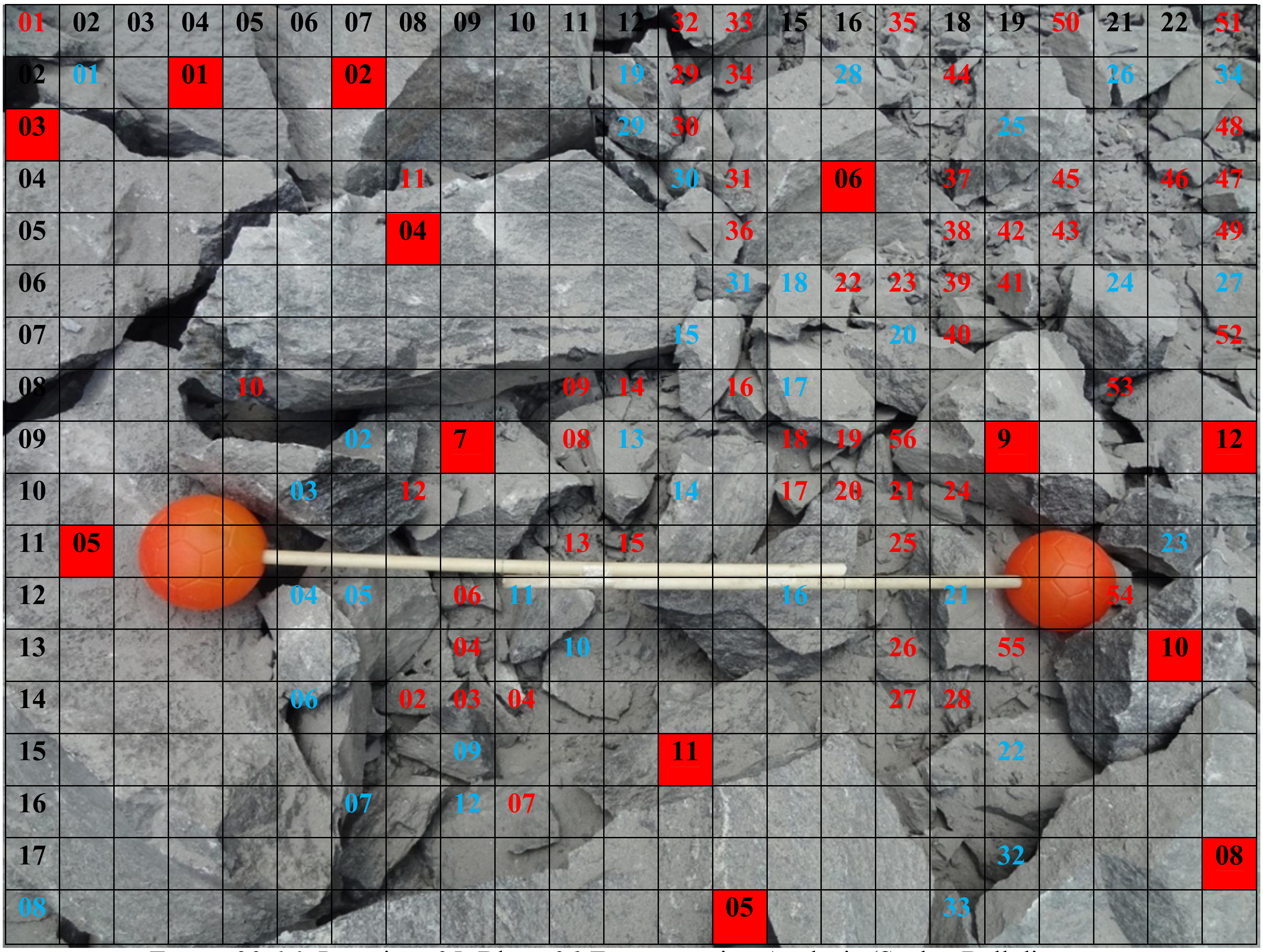

Figure-20.6.1: Location -05, Blast -06-Fragmentation Analysis (Scale : Ball diameter is 20.32 cm)

Table- 16.6: Fragmentation Analysis of location -05, blast – 06 of *Figure-20.6.1*

Size of fragments (Inches)	Numbers of fragments	Average
1-6	224	68.712%
6-9 (Red colour)	**56**	17.178%
9-15 (Blue colour)	**34**	10.429%
15< Boulders (Red Bold)	12	3.680%
Total	326	

Field application details are summarized as below Table-17, regarding the above location-05, six bore hole blasting.

4.5.3. Comparison of the blasted location-05

Table-17: The summary of Six boreholes blasting at location-05

Number of Borehole	01	02	03	04	05	06
Borehole diameter (mm)	38	38	38	38	38	38
Borehole depth (m)	1.524	1.524	1.524	1.524	1.524	1.524
Burden (m)	0.914	0.914	0.914	0.914	0.914	0.914
Emulsion (kg)	0.13	0.13	0.13	0.13	0.13	0.13
Plain Detonator (No.)	01	01	01	01	01	01
AN/FO (kg)	0.35	0.35	0.35	0.35	0.35	0.35
Stemming (m)	0.6096	0.6096	0.6096	0.6096	0.6096	0.6096
Explosive Column height (m)	0.914	0.914	0.914	0.914	0.914	0.914
Fly rock thrown distance-m	9	12	10	9	12	6
Fragment scattered area-m^2	8	8	6	9	8	9
Material quantity after blasting. (Cube)	2.5	2	2.5	3	1.5	1.5
Material quantity after blasting. (m^3)	7.08	5.66	7.08	8.5	4.25	4.25
Specific Charge (kg m^{-3})	0.11	0.14	0.11	0.091	0.19	0.19
Average blasted rock volume	6.14 m^3 (2.17 Cubes)					
Average Specific Charge	0.125 kg m^{-3}					

Average blasted rock volume = 6.14 m^3

Average solid rock volume = 6.14 m^3 / 1.6

Average solid rock volume = 3.84m^3

Average Specific Charge = 0.48kg / 3.84 m^3

= $\underline{\underline{0.125\ kgm^{-3}}}$

4.6. Selected quarry location-06

Quarry Address	-	Kegalle
District	-	Kegalle
Divisional Secretariat	-	Kegalle
Coordinates	-	219866N, 153129E

Quarry site is situated at Thelpeniwala village. In order to reach the quarry, one has to turn to left from the Ussapitiya junction, and proceed along the Malawita road. Ussapitiya junction is located 6.5 km away from Kegalle town of Colombo-Kandy main road. After proceeding about 3.5 km distance along the Malawita carpet road is end at Malawita and turn right and go straight to half kilometer and then quarry is appeared.

Figure-21: Sample rock , Banded biotite gneiss rock with well developed foliation.

4.6.1. Selection of rock surface and preparation for testing at location-06

Carefully selected the good systematic, uninterrupted, no weathered surface without joints, fractures or cracks. Selected area has enough solid surface to blast. Clear to observe the blasting yield, thus remove all the muck files and clean the quarry, before doing the field application.

4.6.2. Field Application Details at location-06

To get the idea of fragments, that took the photograph of each blast with 20.32 cm ball (scale) and then can calculate the separation of boulder size and count the number of boulders. The fly rock thrown distance of each blast is significant value and average value is 10.3m of location no.06. For details to see table-19. Absorption of blasting energy to rock, most probably is consumed to production and fragmentation of the rock. Detonation energy of emulsion primer charge is highly adopted to the hardness of rock, therefore the production is the highest and input the maximum energy of primer charge to activate the rock breakage. See *Figures from 21.1 to 21.6.1.*

Figure-21.1: Location - 06, Blast -01- (Scale: Ball diameter is 20.32 cm)

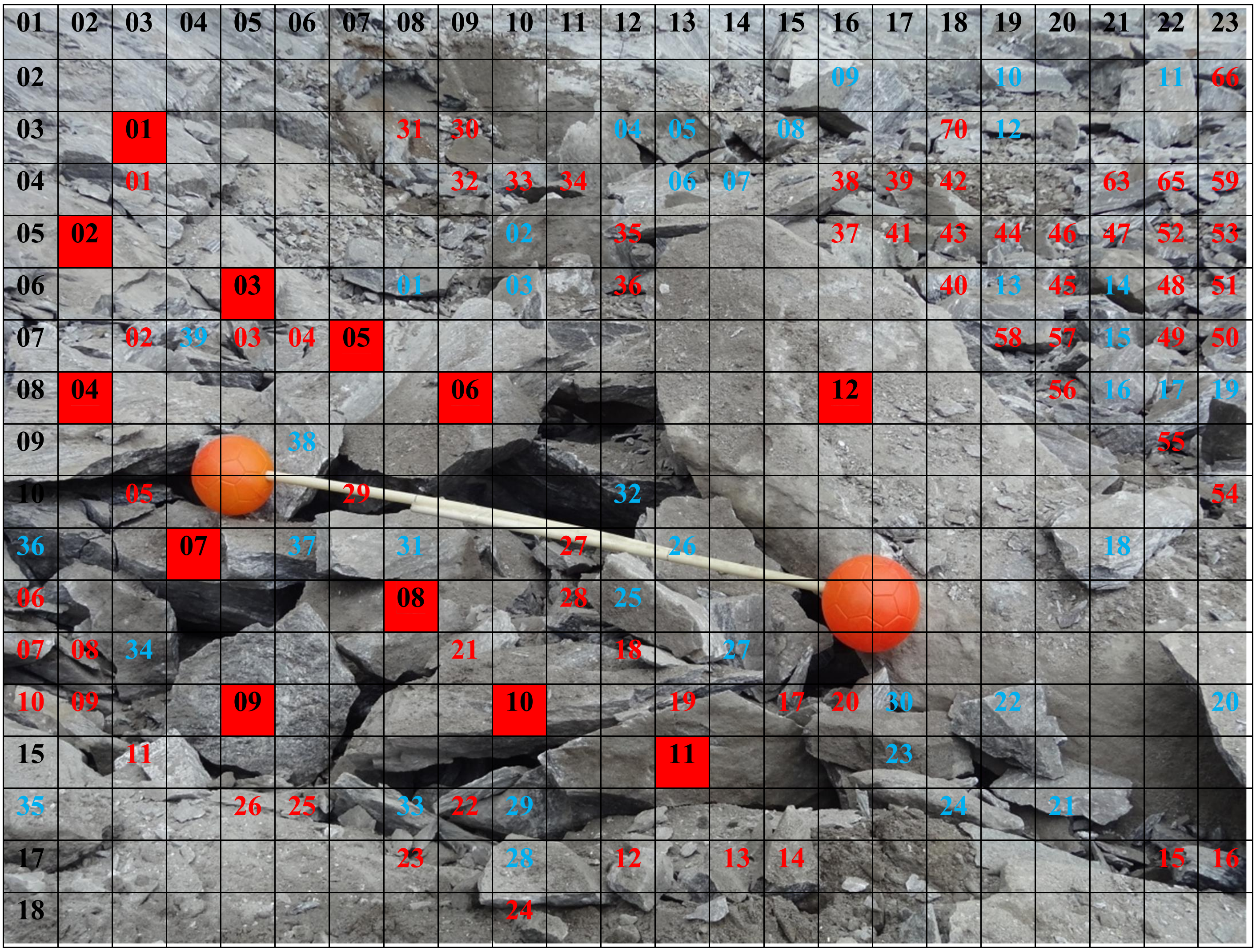

Figure-21.1.1 :Location - 06, Blast -01-Fragmentation analysis (Scale : Ball diameter is 20.32 cm)

Table- 18.1: Fragmentation Analysis of Location - 06, blast – 01 of *Figure-21.1.1*

Size of fragments (Inches)	Numbers of fragments	Average
1-6	615	83.559%
6-9 (Red colour)	**70**	9.511%
9-15 (Blue colour)	**39**	5.299%
15< Boulders (Red Bold)	12	1.630 %
Total	736	

Figure-21.2: Location - 06, Blast -02- (Scale: Ball diameter is 20.32 cm)

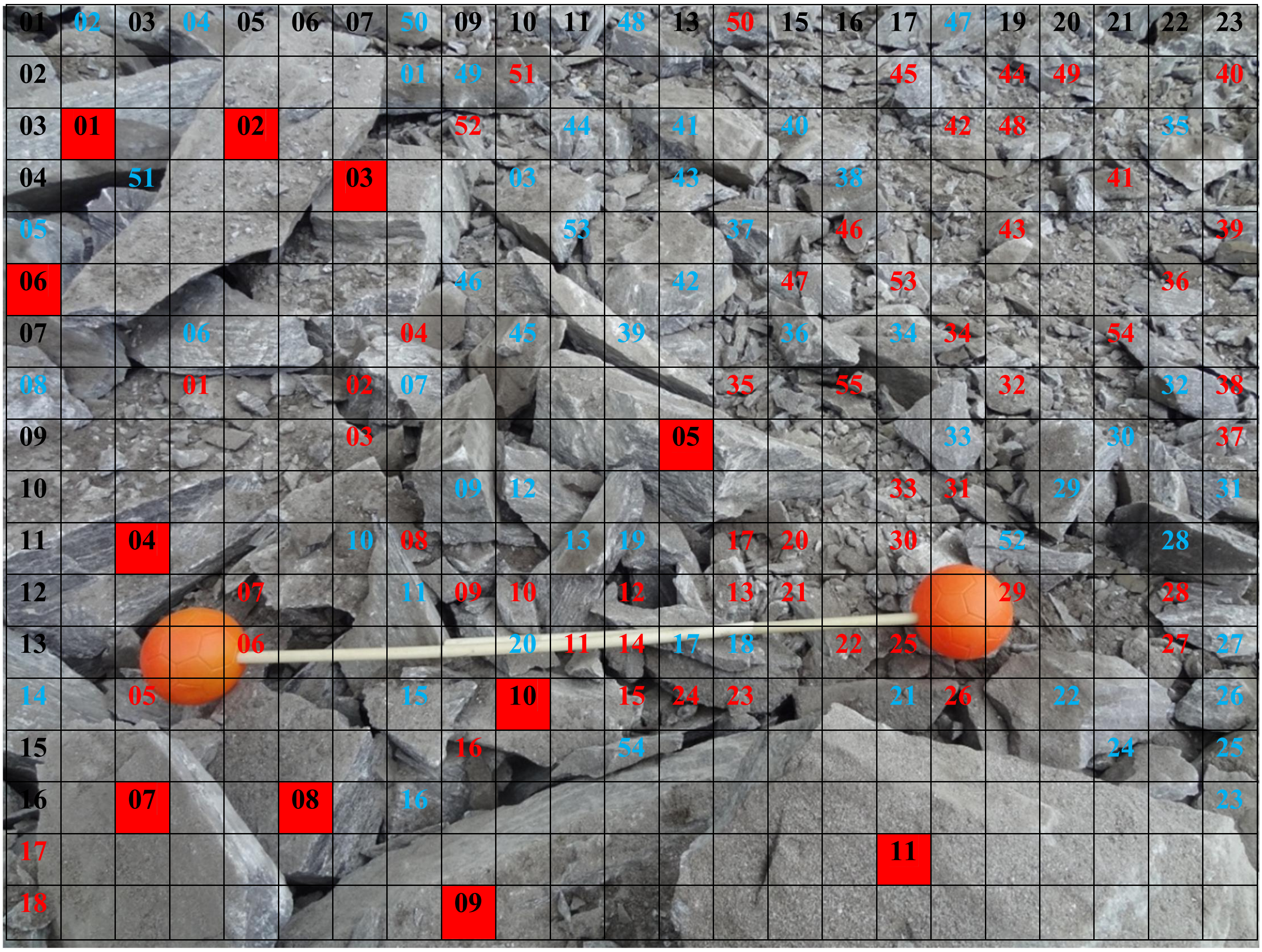

Figure-21.2.1: Location - 06, Blast -02 -Fragmentation analysis (Scale : Ball diameter is 20.32 cm)

Table- 18.2: Fragmentation Analysis of Location - 06, blast – 02 of *Figure-21.2.1*

Size of fragments (Inches)	Numbers of fragments	Average
1-6	438	78.495%
6-9 (Red colour)	**55**	9.856%
9-15 (Blue colour)	**54**	9.677%
15< Boulders (Red Bold)	11	1.971%
Total	558	

Figure-21.3: Location - 06, Blast -03- (Scale: Ball diameter is 20.32 cm)

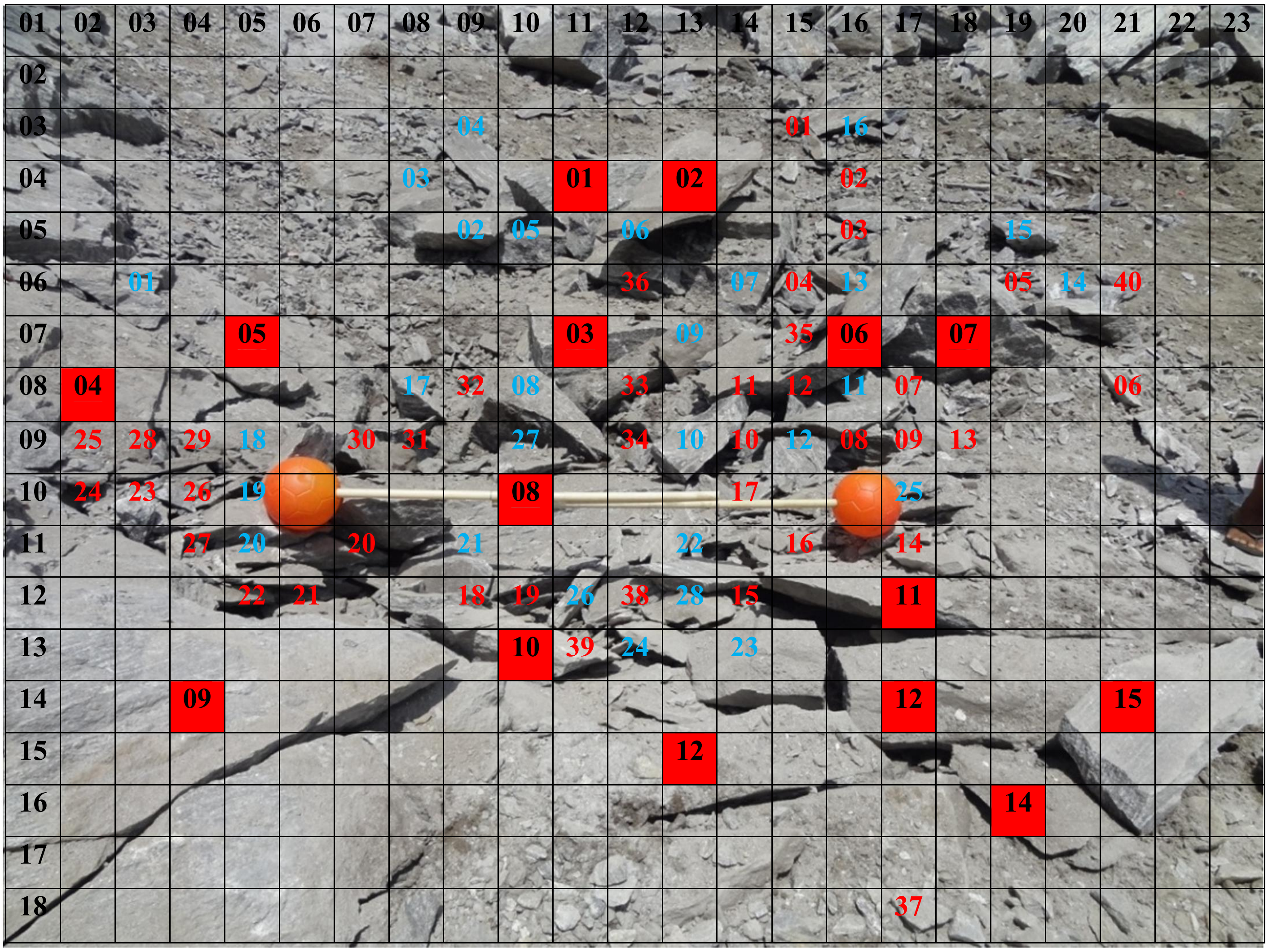

Figure-21.3.1: Location - 06, Blast -03,Fragmentation analysis (Scale : Ball diameter is 20.32 cm)

Table- 18.3: Fragmentation Analysis of Location - 06, blast – 03 of *Figure-21.3.1*

Size of fragments (Inches)	Numbers of fragments	Average
1-6	397	82.708%
6-9 (Red colour)	**40**	8.333%
9-15 (Blue colour)	**28**	5.833%
15< Boulders (Red Bold)	15	3.125%
Total	480	

Figure-21.4: Location - 06, Blast -04- (Scale: Ball diameter is 20.32 cm)

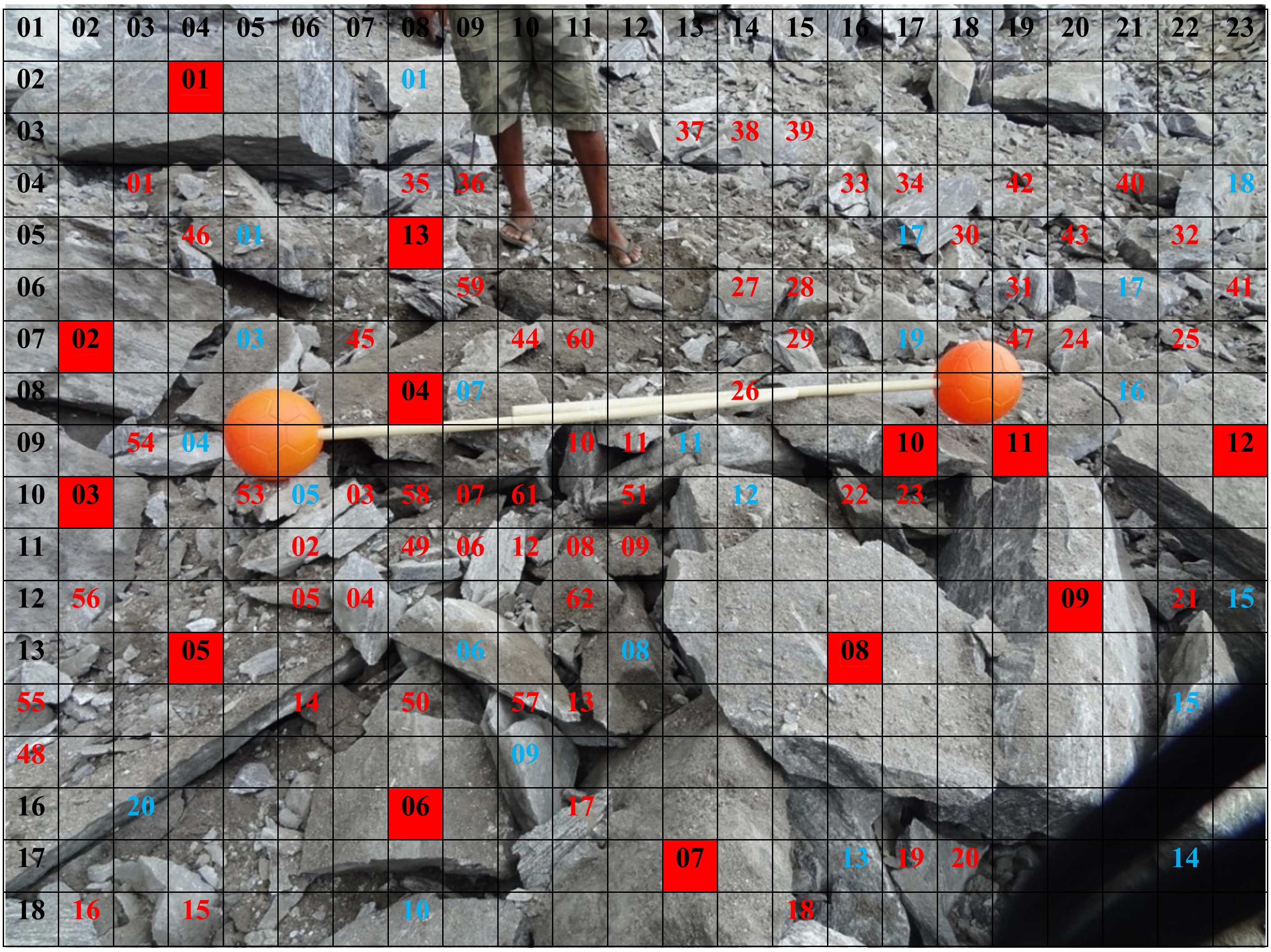

Figure-21.4.1: Location - 06, Blast -04, Fragmentation analysis (Scale : Ball diameter is 20.32 cm)

Table-18.4: Fragmentation Analysis of Location - 06, blast – 04 of *Figure-21.4.1*

Size of fragments (Inches)	Numbers of fragments	Average
1-6	568	85.671
6-9 (Red colour)	**62**	9.351%
9-15 (Blue colour)	**20**	3.017%
15< Boulders (Red Bold)	13	1.961%
Total	663	

Figure-21.5: Location - 06, Blast -05(Scale: Ball diameter is 20.32 cm)

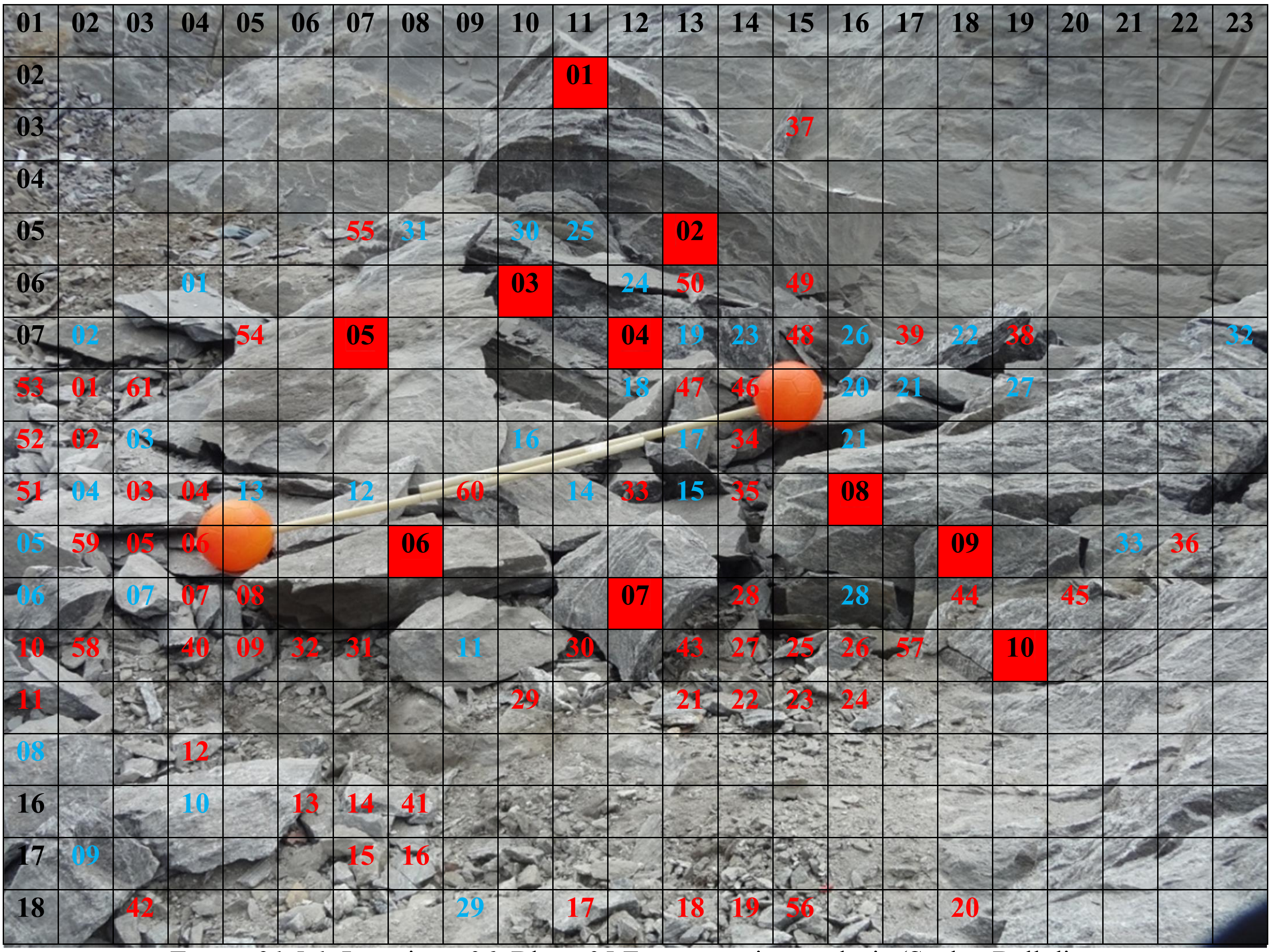

Figure-21.5.1: Location - 06, Blast -05,Fragmentation analysis (Scale : Ball diameter is 20.32 cm)

Table- 18.5: Fragmentation Analysis of Location - 06, blast - 05 of *Figure-21.5.1*

Size of fragments (Inches)	Numbers of fragments	Average
1-6	238	69.591%
6-9 (Red colour)	**61**	17.836 %
9-15 (Blue colour)	**33**	9.649%
15< Boulders (Red Bold)	10	2.924%
Total	342	

Figure-21.6: Location - 06, Blast -06(Scale: Ball diameter is 20.32 cm)

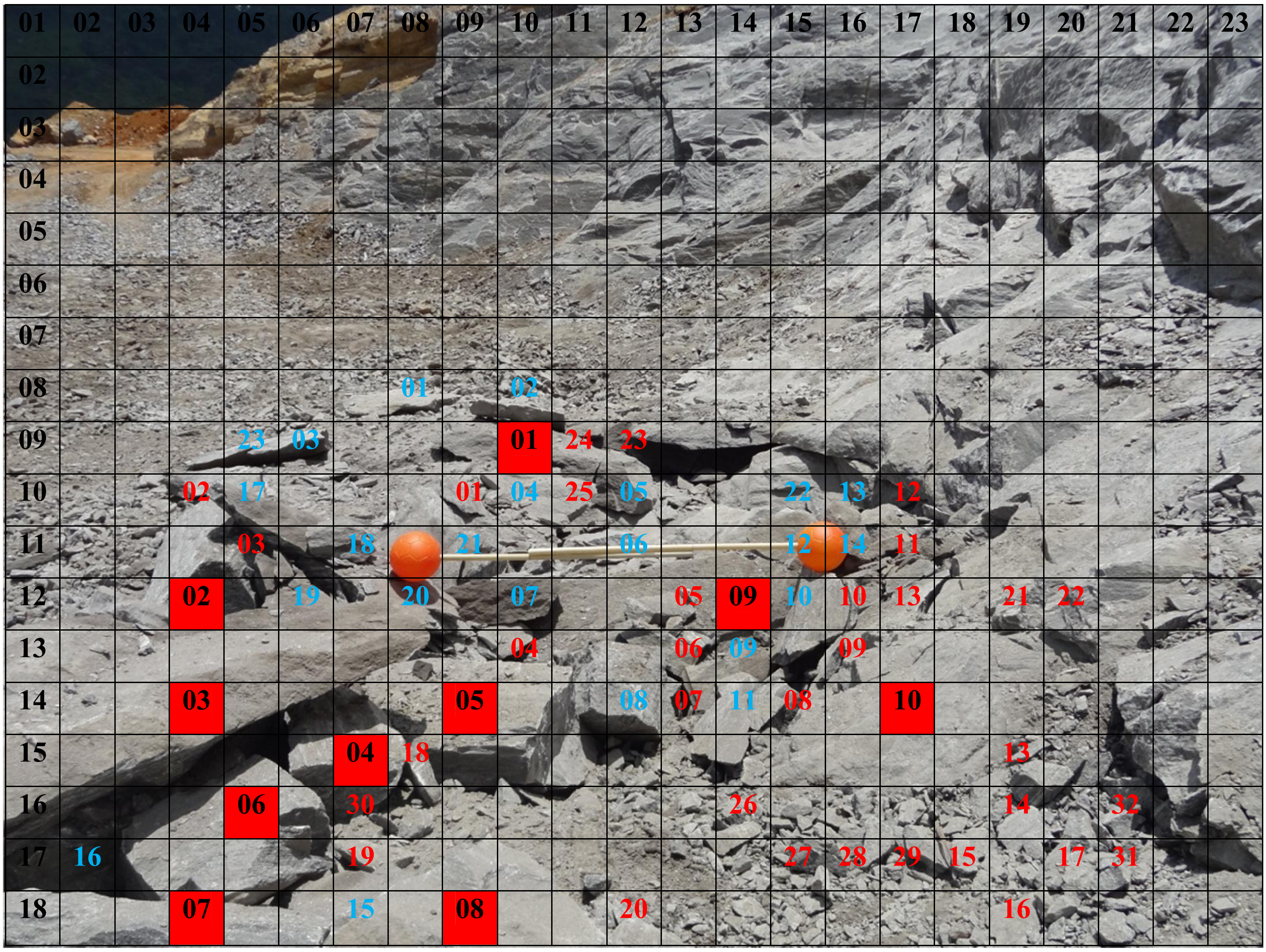

Figure-21.6.1: Location - 06, Blast -06, Fragmentation analysis (Scale : Ball diameter is 20.32 cm)

Table- 18.6: Fragmentation analysis of Location - 06, blast-06of *Figure-21.6.1*

Size of fragments (Inches)	Numbers of fragments	Average
1-6	317	82.552%
6-9 (Red colour)	**32**	8.333%
9-15 (Blue colour)	**25**	6.510%
15< Boulders (Red Bold)	10	2.604 %
Total	384	

Field application details are summarized as below Table-19, regarding the above location-06, six bore hole blasting.

4.6.3. Comparison of the blasted location-06

Table-19: The summary of Six boreholes blasting at location-06

Number of Borehole	**01**	**02**	**03**	**04**	**05**	**06**
Borehole diameter (mm)	38	38	38	38	38	38
Borehole depth (m)	1.524	1.524	1.524	1.524	1.524	1.524
Burden (m)	0.914	0.914	0.914	0.914	0.914	0.914
Emulsion (kg)	0.13	0.13	0.13	0.13	0.13	0.13
Plain Detonator (No.)	01	01	01	01	01	01
AN/FO (kg)	0.35	0.35	0.35	0.35	0.35	0.35
Stemming (m)	0.6096	0.6096	0.6096	0.6096	0.6096	0.6096
Explosive Column height (m)	0.914	0.914	0.914	0.914	0.914	0.914
Fly rock thrown distance-m	12	10	12	8	12	8
Fragment scattered area-m^2	6	5	6	4	6	5
Material quantity after blasting. Cubes	2	1.5	1.5	2	1.5	1.5
Material quantity after blasting. (m^3)	5.66	4.25	4.25	5.66	4.25	4.25
Specific Charge (kg m^{-3})	0.14	0.19	0.19	0.14	0.19	0.19
Average blasted rock volume	4.72 m^3 (1.66 Cubes)					
Average Specific Charge	0.163 kg m^{-3}					

Average blasted rock volume = 4.72 m^3

Average solid rock volume = 4.72 m^3 / 1.6

Average solid rock volume = 2.95m^3

Average Specific Charge = 0.48kg / 2.95 m^3

= 0.163 kgm^{-3}

CHAPTER - 05

5. FRAGMENTATION SUMMARY

5.1. Selected quarry location-01

Location-01 - GalkotuwaWatta, Diyagama, Hiriwdunna.
Coordinates - 230873N, 158031E

5.1.1. Brief summary of fragmentation analysis of Blast 01 to Blast 06 (From table 8.1 to table 8.6).

Table -8.1:Fragmentationof -***Figure-16.1.1.*** Blast- 01

Size of fragments(Inches)	Numbers of fragments	Average
1-6	63	45.000 %
6-9	**46**	32.857 %
9-15	**20**	14.286 %
15< Boulders	11	07.857%
Total	140	

Table -8.2: Fragmentation of -*Figure-16.2.1*: Blast -02

Size of fragments(Inches)	Numbers of fragments	Average
1-6	96	51.892 %
6-9	**55**	29.730 %
9-15	**23**	12.432 %
15< Boulders	11	5.946 %
Total	185	

Table -8.3: Fragmentation of -*Figure-16.3.1*: Blast -03

Size of fragments(Inches)	Numbers of fragments	Average
1-6	388	84.165 %
6-9	**47**	10.195%
9-15	**16**	3.47 %
15< Boulders	10	2.169 %
Total	461	

Table -8.4: Fragmentation of -*Figure-16.4.1* : Blast -04

Size of fragments(Inches)	Numbers of fragments	Average
1-6	113	63.128%
6-9	**45**	25.140%
9-15	**11**	6.145%
15< Boulders	10	5.586 %
Total	179	

Table -8.5: Fragmentation of -*Figure-16.5.1* : Blast -05

Size of fragments(Inches)	Numbers of fragments	Average
1-6	87	47.802 %
6-9	**68**	37.363 %
9-15	**16**	8.791%
15< Boulders	11	6.044%
Total	182	

Table -8.6: Fragmentation of -*Figure-16.6.1* : Blast -06

Size of fragments(Inches)	Numbers of fragments	Average
1-6	263	70.889 %
6-9	**83**	22.372%
9-15	**13**	3.504 %
15< Boulders	12	3.234%
Total	371	

Table -20: Fragmentation Summary of location-01, table 8.1 to 8.6

Rock Characteristic		**Average Fragments Percentage (Inches)**			
Location No:	AIV	(1 - 6) %	(6 - 9) %	(9 - 15) %	(15<-) %
01	30	60.479	26.276	8.105	5.139

5.2. Selected quarry location-02

Location-02 - Dorawaka, Warakapola
Coordinates - 222884N, 136598E

5.2.1. Brief summary of fragmentation analysis of Blast 01 to Blast 06 (From table 10.1 to table 10.6).

Table -10.1: Fragmentation of -*Figure-17.1.1* : Blast -01

Size of fragments(Inches)	**Numbers of fragments**	Average
1-6	**580**	86.309 %
6-9	**51**	7.589 %
9-15	**19**	2.827%
15< Boulders	**22**	3.273%
Total	672	

Table -10.2: Fragmentation of -*Figure-17.2.1* : Blast -02

Size of fragments(Inches)	Numbers of fragments	Average
1-6	206	80.469 %
6-9	**22**	8.594%
9-15	**16**	6.250 %
15< Boulders	12	4.687%
Total	256	

Table -10.3: Fragmentation of - *Figure-17.3.1* : Blast -03

Size of fragments(Inches)	Numbers of fragments	Average
1-6	102	57.954%
6-9	**33**	18.75 %
9-15	**23**	13.068%
15< Boulders	18	10.227%
Total	176	

Table -10.4: Fragmentation of - *Figure-17.4.1* : Blast -04

Size of fragments(Inches)	Numbers of fragments	Average
1-6	368	83.069%
6-9	**34**	7.675%
9-15	**19**	4.289%
15< Boulders	22	4.966%
Total	443	

Table -10.5: Fragmentation of -*Figure-17.5.1* : Blast -05

Size of fragments(Inches)	Numbers of fragments	Average
1-6	290	83.574%
6-9	**26**	7.492%
9-15	**24**	6.916 %
15< Boulders	07	2.017%
Total	347	

Table -10.6: Fragmentation of -*Figure-17.6.1* : Blast -06

Size of fragments(Inches)	Numbers of fragments	Average
1-6	294	84.241%
6-9	**26**	7.449%
9-15	**20**	5.731%
15< Boulders	09	2.578%
Total	349	

Table -21: Fragmentation Summary of location-02, table 10.1 to 10.6

Rock Characteristic		**Average Fragments Percentage (Inches)**			
Location No:	AIV	(1 - 6) %	(6 - 9) %	(9 - 15) %	(15<-) %
02	22	79.269	9.591	6.513	4.625

5.3. Selected quarry location-03

Location-03 - Deloluwaw, Deraniyagala
Coordinates - 195006N, 149038E

5.3.1. Brief summary of fragmentation analysis of Blast 01 to Blast 06 (From table 12.1 to table 12.6).

Table -12.1: Fragmentation of -*Figure-18.1.1*:Blast -01

Size of fragments(Inches)	Numbers of fragments	Average
1-6	267	74.581%
6-9	**50**	13.966%
9-15	**24**	6.704%
15< Boulders	17	4.749%
Total	358	

Table -12.2: Fragmentation of -*Figure-18.2.1* : Blast -02

Size of fragments(Inches)	Numbers of fragments	Average
1-6	222	67.683 %
6-9	**69**	21.037%
9-15	**25**	07.622%
15< Boulders	12	3.658 %
Total	328	

Table -12.3: Fragmentation of -*Figure-18.3.1* :Blast -03

Size of fragments(Inches)	Numbers of fragments	Average
1-6	76	43.678%
6-9	**54**	31.034%
9-15	**28**	16.092%
15< Boulders	16	09.195%
Total	174	

Table -12.4: Fragmentation of -*Figure-18.4.1*: Blast -04

Size of fragments(Inches)	Numbers of fragments	Average
1-6	288	71.820%
6-9	**63**	15.711%
9-15	**38**	9.476%
15< Boulders	12	2.992%
Total	401	

Table -12.5: Fragmentation of -*Figure-18.5.1* :Blast -05

Size of fragments(Inches)	Numbers of fragments	Average
1-6	128	54.008%
6-9	**74**	31.224%
9-15	**24**	10.126%
15< Boulders	11	4.641%
Total	237	

Table -12.6: Fragmentation of -*Figure-18.6.1* : Blast -06

Size of fragments(Inches)	Numbers of fragments	Average
1-6	168	69.709%
6-9	**41**	17.012%
9-15	**19**	07.884%
15< Boulders	13	5.394%
Total	241	

Table -22: Fragmentation Summary of location-03, tables 12.1 to12.6

Rock Characteristic		**Average Fragments Percentage (Inches)**			
Location No:	AIV	(1 - 6) %	(6 - 9) %	(9 - 15) %	(15<-) %
03	22	63.580	21.664	9.651	5.105

5.4. Selected quarry location-04

Location-04 - Kannathtota, Ruwanwella
Coordinates - 211125N, 142884E

5.4.1. Brief summary of fragmentation analysis of Blast 01 to Blast 06 (From table 14.1 to table 14.6).

Table -14.1: Fragmentation of*Figure-19.1.1* : Blast -01

Size of fragments(Inches)	Numbers of fragments	Average
-6	412	76.438%
6-9	73	13.543%
9-15	45	8.349%
15< Boulders	09	1.669%
Total	539	

Table -14.2: Fragmentation of*Figure-19-2.1* : Blast -02

Size of fragments(Inches)	Numbers of fragments	Average
1-6	270	75.843%
6-9	41	11.516%
9-15	38	10.674%
15< Boulders	07	1.966%
Total	356	

Table -14.3: Fragmentation of -*Figure-19-3.1* : Blast -03

Size of fragments(Inches)	Numbers of fragments	Average
-6	152	59.375%
6-9	61	23.828%
9-15	33	12.891%
15< Boulders	10	3.906 %
Total	256	

Table -14.4: Fragmentation of *Figure-19.4.1* : Blast -04

Size of fragments(Inches)	Numbers of fragments	Average
1-6	83	41.708%
6-9	65	32.663%
9-15	41	20.603%
15< Boulders	10	5.025%
Total	199	

Table -14.5: Fragmentation of *Figure-19.5.1* : Blast -05

Size of fragments(Inches)	Numbers of fragments	Average
1-6	144	48.160%
6-9	93	31.104%
9-15	53	17.725%
15< Boulders	09	3.010%
Total	299	

Table -14.6: Fragmentation of *Figure-19.6.1* : Blast -06

Size of fragments(Inches)	Numbers of fragments	Average
1-6	298	71.291%
6-9	75	17.942%
9-15	35	8.373%
15< Boulders	10	2.392%
Total	418	

Table -23: Fragmentation Summary of location-04, table 14.1 to 14.6

Rock Characteristic		**Average Fragments Percentage (Inches)**			
Location No:	AIV	(1 - 6) %	(6 - 9) %	(9 - 15) %	(15<-) %
04	28	62.134	21.766	13.102	2.995

5.5. Selected quarry location-05

Location-05 - Diwulapitiya
Coordinates - 231075N, 124322E

5.5.1. Brief summary of fragmentation analysis of Blast 01 to Blast 06 (From table 16.1 to table 16.6).

Table -16.1: Fragmentation of -*Figure-20.1.1* : Blast -01

Size of fragments(Inches)	Numbers of fragments	Average
1-6	81	46.023%
6-9	**48**	27.272 %
9-15	**33**	18.75%
15< Boulders	14	7.954%
Total	176	

Table -16.2: Fragmentation of -*Figure-20.2.1* : Blast -02

Size of fragments(Inches)	Numbers of fragments	Average
1-6	114	56.716%
6-9	**47**	23.383%
9-15	**28**	13.930%
15< Boulders	12	5.970%
Total	201	

Table -16.3: Fragmentation of -*Figure-20.3.1* : Blast -03

Size of fragments(Inches)	Numbers of fragments	Average
1-6	106	52.475%
6-9	**54**	26.733%
9-15	**27**	13.366 %
15< Boulders	15	7.425%
Total	202	

Table -16.4: Fragmentation of -*Figure-20.4.1* : Blast -04

Size of fragments(Inches)	Numbers of fragments	Average
1-6	237	65.110%
6-9	**74**	20.329%
9-15	**30**	8.242%
15< Boulders	23	6.318%
Total	364	

Table -16.5: Fragmentation of -*Figure-20.5.1* : Blast -05

Size of fragments(Inches)	Numbers of fragments	Average
1-6	411	75.830%
6-9	**91**	16.790%
9-15	**30**	5.535%
15< Boulders	10	1.845%
Total	542	

Table -16.6: Fragmentation of -*Figure-20.6.1* : Blast -06

Size of fragments(Inches)	Numbers of fragments	Average
1-6	224	68.712%
6-9	**56**	17.178%
9-15	**34**	10.429%
15< Boulders	12	3.680%
Total	326	

Table -24: Fragmentation Summary of location-05, table 16.1 to 16.6

Rock Characteristic		**Average Fragments Percentage (Inches)**			
Location No:	AIV	(1 - 6) %	(6 - 9) %	(9 - 15) %	(15<-) %
05	27	60.811	21.947	11.709	5.532

5.6. Selected quarry location-06

Location-06 - Kegalle
Coordinates - 219866N, 153129E

5.6.1. Brief summary of fragmentation analysis of Blast 01 to Blast 06 (From table 18.1 to table 18.6).

Table -18.1: Fragmentation of -*Figure-21.1.1* : Blast -01

Size of fragments(Inches)	Numbers of fragments	Average
1-6	615	83.559%
6-9	**70**	9.511%
9-15	**39**	5.299%
15< Boulders	12	1.630 %
Total	736	

Table -18.2: Fragmentation of -*Figure-21.2.1* : Blast -02

Size of fragments(Inches)	Numbers of fragments	Average
1-6	438	78.495%
6-9	**55**	9.856%
9-15	**54**	9.677%
15< Boulders	11	1.971%
Total	558	

Table -18.3: Fragmentation of -*Figure-21.3.1* : Blast -03

Size of fragments(Inches)	Numbers of fragments	Average
1-6	397	82.708%
6-9	**40**	8.333%
9-15	**28**	5.833%
15< Boulders	15	3.125%
Total	480	

Table -18.4: Fragmentation of -*Figure-21.4.1* : Blast -04

Size of fragments(Inches)	Numbers of fragments	Average
1-6	568	85.671
6-9	**62**	9.351%
9-15	**20**	3.017%
15< Boulders	13	1.961%
Total	663	

Table -18.5: Fragmentation of -*Figure-21.5.1* : Blast -05

Size of fragments(Inches)	Numbers of fragments	Average
1-6	238	69.591%
6-9	**61**	17.836 %
9-15	**33**	9.649%
15< Boulders	10	2.924%
Total	342	

Table -18.6: Fragmentation of -*Figure-21.6.1* : Blast -06

Size of fragments(Inches)	Numbers of fragments	Average
1-6	317	82.552%
6-9	**32**	8.333%
9-15	**25**	6.510%
15< Boulders	10	2.604 %
Total	384	

Table -25: Fragmentation Summary of location-06, tables 18.1 to 18.6

Rock Characteristic		**Average Fragments Percentage (Inches)**			
Location No:	AIV	(1 - 6) %	(6 - 9) %	(9 - 15) %	(15<-) %
06	32	80.429	10.537	6.664	2.369

Table-26: Fragmentation summary of above six blasts of location 01 to location 06

Rock Characteristic		**Average Fragmentation Percentage (Inches)**			
Location No:	**AIV**	**(1 - 6) %**	**(6 - 9) %**	**(9 - 15) %**	**(15<-) %**
01	30	60.479	26.276	8.105	5.139
02	22	79.269	9.591	6.513	4.625
03	22	63.580	21.664	9.651	5.105
04	28	62.134	21.766	13.102	2.995
05	27	60.811	21.947	11.709	5.532
06	32	80.429	10.537	6.664	2.369

Table-26 shows field application results of six locations with 22 to 32 of aggregate impact value range that the higher aggregate impact value possessing rock types are more prompt to produce the fine production. But according to the Table-27 that their fly rock distance is higher and production rock volume is lower which are not favour to the production cost. Comparing the Table-26 fragmentation of rocks are more favorable.

CHAPTER -06

6. DISCUSSION

6.1. Comparison of rock characteristics with emulsion explosives

The specific charge is an important technical term for both rock and explosives characteristics. The specific charge is related to how much rock is broken and how much explosive is used to break them. It can serve as an indicator of how hard the rock is, or the amount of explosives need to break it. Specific charge can be expressed as a quantity of rock broken by a unit weight of explosives, or it can be expressed the explosives required to break a unit mass a rock. The effectiveness of emulsion explosives primer charge is determined by its detonation pressure. This detonation pressure can perfectly captured by hard rock formation than other soft rocks. Also the detonation pressure transmit to borehole pressure within very small time gap that very small tiny time gap is directly affect to the rock types to capture the whole producing huge amount of energy to use for turning, fly rocks, air over pressure and blasted rock volume. The column charge creates borehole pressure and initiates the fragmentation.

According to the experimental results, that clear shorter fly rock distance and the highest blasted rock volume was belong to the hardest rock type quarry. It was observed that with increasing rock hardness a tendency was to increase blasted rock volume and decrease fly rock distance. This phenomenon clearly describe the primer charge of Emulsion explosive affects with rock types. The detonation pressure transmit to borehole pressure that it has time gap which directly effect to the rock types for fragmentation and blasted rock volume. Consider the field test result, wasting of borehole pressure energy is higher in the soft rock than hard rock. Because of high bore hole crushing ability has soft rock. Therefore the rock belonging to lower aggregate impact value, the specific charge is lower than the soft rock types. Blasting data of field application were gathered to compare in below Table-27.

6.2. Comparison of experimental results

Table-27. Comparison of six rock types blasted with emulsion explosives

Quarry Location	Rock Characteristics	Explosive Specific Charge kg m^{-3}	Average production	Fly rocks thrown distance
No. 01. Kegalle.	Quartz feldspar fine grain, light colourbiotite rock with banding. (leucocratic rock) AIV- 30	0.157 kg m^{-3}	4.96 m^3 (1.75 Cubes)	10.5m
No. 02. Warakapola	Massive charnockite (fine grain) rock. AIV- 22	0.094 kg m^{-3}	8.27m^3 (2.92 Cubes)	5.2m
No. 03. Deraniyagala	Banded charnockite (fine grain) rock. (Charnockite with occasional banding and 5% > garnet.) AIV- 22	0.097 kg m^{-3}	8.04m^3 (2.84 Cubes)	4.2m
No. 04. Awissawella.	Medium grain size charnockite rock with banded appearance. AIV- 28	0.11kg m^{-3}	7.08m^3 (2.5 Cubes)	7.8m
No. 05. Diulapitiya	Bandedbiotite gneiss rock with 5% > garnet. Foliations are not welldeveloped. AIV- 27	0.126kg m^{-3}	6.14m^3 (2.17 Cubes)	9.7m
No. 06. Kegalle.	Banded biotite gneiss rock with well develop foliation. AIV- 32	0.165 kg m^{-3}	4.7m^3 (1.66 Cubes)	10.3m

Above Table-27 shows the six types of rock formation, that blasted with emulsion explosive and resulting average values of specific charge, production rock volume, and the fly rock distance. Drawing to attention of No. 02 and No. 03 locations respectively, which are belonging to the lowest AIV values, the highest production rock volumes and the shortest fly rock distance locations. Analyzing the above results, effectiveness of emulsion explosives with quarrying in high grade metamorphic rocks in Sri Lanka is more favorable than low grade soften rock types.

Table-28. Average summary of blasting results.

Average range of AIV - (22 - 32)	27
Average Explosive Specific Charge kg m^{-3}	0.125
Average production (Cubes)	2.202
Average Fly rocks thrown distance (m)	7.95
Average Fragments (1 - 6 Inches) %	67.784
Average Fragments (6 - 9 Inches) %	18.63
Average Fragments (9 -15 Inches)%	9.291
Average Fragments (15< - Inches)%	4.294

Consider the AIV range between 22 to 32 rock types, the average summary of above Table-28 favorable fragmentation is more than 95% . Study of the practical results of Table-27 is given by the evidences for the reaction of emulsion explosives with hard rock formation.

Table-28 explains the aggregate impact value (AIV) is higher than 27, the specific charge is higher, fly rock thrown distance is higher and the production rock volume is lower. The lower aggregate impact value is vice versa. Quarrying with higher AIV values possessing rock types, want to carefully select the emulsion primer charge weight. Otherwise it has to fly rock effect and higher blasting cost.

CHAPTER-07

7. CONCLUSION AND RECOMMENDATIONS

To obtain well fragmented rock by blasting, explosive energy must be well distributed throughout the rock. To be affected in rock blasting, this energy must be applied at the proper way to allow for optimum rock movement. Energy distribution within a shot is measured by the energy factor, which compare the explosive energy to quantity of rock broken. The explosive energy distribution within the entire blast is then evaluated along with its resulting rock volume and fragmentation. Blasting analysis next become a function of the explosive energy, fragmentation results, and subsequent production of rock volume. Proper energy distribution is important in obtaining the desired rock breakage and movement of energy from bottom to toe of the bore hole.

The suitability and to evaluate the performance of emulsion explosive with Sri Lankan metamorphic rocks is essential. This study was aimed that the emulsion explosives are reacted with the different rock types. Selected rock types for this study were compared as above Table-27, which are denoted the major metamorphic rock types in Sri Lanka. The hardness of the selected rocks have widely distributed range and using them for construction works in island wide.

According to Table-27, that the field application results were observed, emulsion explosives reacted with hard rock, had low value of specific charge used for rock breaking other than higher aggregate impact value possessing rocks. Table-27, location, 02 and 03, average blasting results indicate that production rock volume is higher and fly rock distance is shorter than other higher aggregate impact value possessing rock locations. Further analysis of that reason, considering the rock breakage, without capturing properly by rock, large amount of gas pressure energy wasting and losing true immature cracks, duration in primer charge detonation of soft rocks. This means bore hole crushing and crack formation of soft rock is faster than hard rock.

Carefully observed throughout the field test results, emulsion primer charge detonation and formation of radial cracks with soft rock is faster than hard rock. According to this, duration of detonation phenomenon, large fraction of energy wasting without doing proper work with rock. The results are reduction of blasted rock volume, low fragmentation, more boulder formation and high fly rock distance.

These experimental results gave that one of rock characteristic as AIV value, that using with emulsion explosives for breaking to fragments of rock, as indicator. Compare with rock types and hardness of rock, reduce or induce the amount of explosives to balance the energy requirement to break them. The aggregate impact value (AIV) is higher, the specific charge is higher, fly rock distance is higher and the production rock volume is lower which are not favour to the production cost. The less strength rock type wants less amount of primer charge than harder rock types for better results.

Compare with rock types and hardness of rock, reduce or induce the usage of emulsion explosive to balance the energy requirement. Rock strength is poor that can transmit primer charge detonation pressure poorly to borehole pressure and create fly rock and boulders. Avoiding this effect have to reduce usage of emulsion explosives quantity according to the hardness of breaking rock. Considering the aggregate impact value of rock, it is good indicator that should be selected the proportional usage of primer charge of emulsion weight according to AIV is recommanded.

Carefully selected the explosive amount of primer charge that can be controlled suggested fragment sizes, blasted rock volume and fly rock distance with field experience of rock types. Identification of rock types and hardness of rock is very important to predict the usage of emulsion explosives weight.

REFERENCES :

01. http://www.learner.org/interactives/rockcycle/index.html

02. http://www.sljol.info/index.php/JNSFSL/article/view/157/298

03. Comprehensive Technical Report for Emulsion By Eng. Saurabh Roy, India.

04. Correlations between Some Strength Properties of Metamorphic Rocks of Sri LankaU.de.S.Jayawardena (Department of Civil Engineering, University ofPeradeniya, Sri Lanka.)

05. http://www.learner.org/interactives/rockcycle/index.html

06. http://www.nps.gov/parkhistory/online_books/npsg/explosives/Chapter8.pdf

07. https://flexiblelearning.auckland.ac.nz/rocks_minerals/rocks/metamorphic.html

08. Rock Blasting and Explosives engineering By Per-Anders Persson, Professor of Mining Engineering and Director, research centre for Energetic Materials, New Mexico institute of mining and Technology, New Mexico, USA. , Roger Holmberg, Vice President and Technical Director, Nitro Nobel AB, Sweden., Jaimin Lee, Senior Research Scientist, Agency of Defense Development, Teajon, Korea. (https://books.google.lk/books?id=sdLO5HESJwgC&pg=PA76&lpg=PA76&dq=rock+blasting+emulsion&source=bl&ots=TIx5Xw0c6&sig=LsNyvsQ7ExeHfVr6wWkrpVVcyWA&hl=en&sa=X&ved=0ahUKEwid46q7_zMAhUNUI8KHd2WBzUQ6AEIGjAA#v=onepage&q=rock%20blasting%20emulsion&f=false)

09. Mineral Resource Of Sri Lanka By L.J.D.Fernando, Former Director, Geological Survey.

10. Explosives and Rock Blasting, Field Technical Operations, Atlas Power company,The USA

11. https://law.resource.org/pub/in/bis/S02/is.6609.2.1.1973.pdf

12. SS (1974) SS73 : Specification for methods for sampling and testing of mineral aggregates, sand and filling - Determination of aggregate impact value.Singapore standard.

13. Millard, R.S. (1993) Road building in the Tropics. Transport Research Laboratory, state-of-the-art review 9,HMSO, London.

14. https://miningandblasting.wordpress.com/

15. http://www.posiva.fi/files/4019/WR_2015-10.pdf.Uniaxial compressive strength

16. http://www.mdpi.com/2075-163X/5/2/276/htm

17. https://www.sp.se/en/index/services/rockmechanicaltesting/uniaxial/Sidor /default.aspx

18. https://en.wikipedia.org/wiki/Compressive_strength

19. http://ceae.colorado.edu/~amadei/CVEN5768/PDF/NOTES8.pdf

20. https://miningandblasting.wordpress.com/

21. https://www.sp.se/en/index/services/rockmechanicaltesting/ indirecttensilestrength/ Sidor/default.aspx

22. Pyrotechnics Guild International Bulletin, No.80 (1992) by K.L and B.L.Kosanke.

23. Test Method For Explosives by MuhamedSuceska.

24. [Source - Indian Standard, Method Of Test For Commercial Blasting Explosives And Accessories, Part II Explosives, Section I Explosives, General.]-Dautriche (D'Autriche) method

25. https://www.nps.gov/parkhistory/online_books/npsg/explosives/Chapter7.pdf (2016.10.16) Priming Charge)

26. ***Figure - 6.*** Schematic illustration of tension crack length and density around blasthole. (Source :Practical application of this theory was demonstrated by Torbica and Lapcevic (2014) for the estimation of blasted rock fragmentation).[TORBICA, S., LAPCEVIC, V. Rock breakage by explosives. ***European International Journal of Science and Technology,*** p. 96-104, 2014.][Links] (2016.10.16)

26. Operation manual - ENKAY AGGREGATE IMPACT TESTER.

27. http://www.enkaymachine.com/products-detail.php?cat=Ng==&product=MjYy (2017.04.01)

28. Rock and aggregate laboratory manual, geotechnical Laboratory, DGM, Thimphu, Bhutan. International Society for rock mechanics suggested methods "Rock Characterization, testing and Monitoring" Editor E.T.Brown, Pergamon Press 1981, Page 113 to 114

29. Rock and aggregate laboratory manual, geotechnical Laboratory, DGM, Thimphu, Bhutan. "Suggested method for determining point load strength" int, Journal Rock Mech.Min.Sc. Vol.22,No.2,pp.51-60 1985].

30. International Society for rock mechanics suggested methods "Rock characterization, testing and monitoring" Editor E.T,Brown, Pergamon Press 1981, pages 119 to121, ASTM Standard Test Method D3967-81.

31. Rock and aggregate laboratory manual, geotechnical Laboratory, DGM, Thimphu, Bhutan. ASTM Standard Test Method C131 - 96.

32. www.enkaymachine. com

33. International Society for Rock Mechanics Suggested Methods "Rock Characterization, Testing And Monitoring" Editor E.T,Brown, Pergamon Press1981,pages 81 to 85. ASTM Standard Test Method C97-83].[Rock and aggregate laboratory manual, Geotechnical Laboratory, DGM, Thimphu, Bhutan].

34. The constructor civil Engineering Home. https://theconstructor.org/building/building-material/specific-gravity-and-water-absorption-test/1358/

35. http://www.pavementinteractive.org/coarse-aggregate-specific-gravity/ (2017.04.15)