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IMPROVING PERFORMANCE AND SAFETY OF USED CIVIL EXPLOSIVES IN PRODUCTION OF SOME SUDANESE ROCKS

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ABSTRACT

The main targets of the civil explosives applied in rock production area, are controlling of fly rocks as safety value and controlling of fragmentations size as performance value. These targets are achieved throughout the studying and analyzing of the effective factors such as density and type of explosive, type of rock, diameter of drilling, and depth of burial. This work deals with improving performance and safety of used civil explosives in production of rocks of different types and applications in the Sudan. This includes marble site in Atbara, diorite site in Alseleet, and granite site in Kassala. It is found that the tables and references of blasting design, like Langforce tables of standards, can be replaced by the tables found by this study as a reliable data. The economical analysis shows the main gain of this work.

Keywords

Civil explosives, Bench blasting, Fragmentation, Fly rocks, Langforce theory, Crater Theory.

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1. INTRODUCTION

The explosive conversion called detonation is characterized by that it proceeds with a rate higher than the rate of the sound under condition actually present in the reaction zone, in contrast to military explosive, which are mostly based on uniform molecules, explosive for non military use are composed of oxidizing, reducing, sensitizing, and inert component, In order that the greatest possible explosive or blast effect can be achieved, and that smallest possible amount of the poisonous explosion gases CO and NO are created in the detonation, the mixtures are mostly adjusted to the requiring balance, and it should be done this definition to agree the civil requiring activity [1-3].

Historically the works with explosive in mining, was started in 1627, in that year the miner Casper Weindle detonated in Slovakia the first documented underground explosion, using black powder, from there on, the customary method of driving shafts by Feuersetzen working with miner hammer and iron tools, was slowly replaced, until the second half of the 19th century black powder remained the only explosive used in mining, over 200 years after black powder was first used [4]. Next came the discovery of nitroglycerin in1846 by Ascanio Sobrero. However, not much could be done with the liquid NG because of its extreme sensitivity. For many years attempts to pour liquid nitroglycerin into boreholes often ended tragedy [5].

In 1864, Alfred Nobel mixed NG with Kieselguhr and this mixture was manufactured, shipped, and used much safety than liquid NG. Alfred Nobel called this product dynamite (after the Greek dynamis meaning power). [6]

The next major development in the commercial explosives industry came in 1947 when a ship loaded with fertilizer grade ammonium nitrate caught fire and exploded at Texas City. The surrounding area was devastated and 561 lives were lost. Through this calamity, the world became aware of the potential of ammonium nitrate as an explosive virtually overnight. Within the next few years, fuel oil became the most widely used additive to produce a dry blasting agent ammonium nitrate fuel oil (ANFO) [7]

Nowadays the explosives for civilian works include ammonium nitrate, slurry explosive, emulsion explosive, heavy ANFO and dynamite (straight dynamites, ammonia dynamites, blasting gelatin, gelatin dynamites, ammonia gelatin, and semi-gelatin dynamite).[8-11]

The main civilian works and applications that need the use of explosives are: Bench blasting, trench blasting, tunneling, demolition, smooth blasting, underwater blasting, oil explorations, and dimension stone.[12-17]

2. ROCK BLASTING THEORY

2.1 CONCEPT

Blasting theory is one of the most interesting, challenging, and controversial areas of the explosives engineering. It encompasses many areas in the science of chemistry, physics, thermodynamics, shock wave interactions, and rock mechanics. In broad terms, rock breakage by explosives involves the action of an explosive and the response on the surrounding rock mass within the realms of energy, time and mass. In spite of the tremendous amount of research conducted in the last few decades, no single blasting theory has been developed and accepted that adequately explains the mechanisms of rock breakage in all blasting conditions and material types. There is as yet no consistent and widely applicable theory of blasting, but only a number of limited theories, many of which are empirical in nature and based on ideal situations [18].

2.2 THE THEORY OF ROCK BLASTING

Rock fracture resulting from explosion process of explosives load in drill holes depend on the number of free faces, the burden, the hole placement and rock geometry, the physical properties and loading density of the explosive, the type of stemming, the rock structure and mechanical strength, and other factors. Final fragmentation in a bench blasting operation can be attributed to a combination of:

1. Crushing of the rock immediately around the explosive cavity, initial radial fracturing due to tensile tangential stress wave, secondary radial fractures formed at the surface, extension of the initial radial fractures by reflected radial tensile strain, joining of inward propagating radial fractures, tangential fractures formed at the surface, tensile separation and shear of rock at places of weakness in the rock mass, separation of the rock due to reflected radial tensile strain, fracture and acceleration of fragments by strain energy release, further fracture and acceleration of broken rock by late expanding gases; and, pre- existing discontinuities in the rock mass.

While none of these mechanisms can be ignored, explosive- generated radial fractures are crucial in determining the overall fragmentation as Harries and Hengst (1977) and Lownds (1983) showed using simulation models.[19]

2.3 CRATER THEORY

Detailed cratering experiments conducted by Duvall and Atchison with point charges produced valuable data for the theory. Furthermore Livingston quantified his observations and developed the Livingston theory and formed a basis to calculate the charges in blasting. The cratering mechanism follows the previously mentioned theory of rock fragmentation by blasting. The shock wave produced by the explosive creates a crushed zone and then as it proceeds out it produces radial fractures due to tensile failure. Furthermore as it is reflected by the free face it can produce spilling and it also aids the development of the radial cracks. It is worth noting here that spilling occurs in massive brittle rocks. If the tensile failures meet with subsurface failures an isolated fragment is created. In most bench blasts the rock formations have been blasted over in a previous lift, resulting in fractures being open to such a degree that surface reflected tensile failure is minimal and the bulk of the failure proceeds from the borehole outwards. In other cases the rocks are so badly pre-fractured that reflection effects are minimal. The high pressure explosive gases originating at the borehole wall rush into the cracks and attempt to wedge them open. If the burden of the charge is small enough the cracks are opened and the material is expelled [19].

2.4 LANGFORS METHOD FOR BENCH BLASTING

Bench blasting is the most common kind of blasting work; it can be defined as blasting of vertical or close to vertical blast-hole in one or several rows towards a free face. Rock formation is rarely homogeneous, the rock formation in the blast area consist of different type of rock, furthermore fault and dirt seams may change the effect of the explosive in blast.

The value applies to burdens between 1.0 to 10m and can be used for most kind of rock; the basis of the computations of bench blasting will be Langefors formula Dynamex, Emulite, and ANFO. The formula used in the calculation are empirical, but are based on information from thousands of blasts, the experience of the Langefors calculation is so good that it could be considered unnecessary in most blasting operation to make trial blasts, however, local condition may make it necessary for the practical operator to test the theoretical calculation in field (Figure 1) [20].

1- Maximum burden.

For Dynamex $B_{max} = 1.45\sqrt{I_b} * R_1 * R_2$ 1

For Emulite $B_{max} = 1.45\sqrt{I_b} * R_1 * R_2$ 2

For ANFO $B_{max} = 1.36\sqrt{I_b} * R_1 * R_2$ 3

I_b - charge concentration

R_1 - Correction for hole inclination other than 3:1.

R_2 – correction for rock constant other than 0.4.

2- Subdrilling.

$U = 0.3 * B_{max}$ 4

3- Depth of blast-hole

$H = 1.05 (K + U)$ 5

4- Practical burden

$B = B_{max} – E$ 6

5- Practical spacing

$S = 1.25 * B$ **7**

6- Height of the charge

$h_b = 1.3 * B_{max}$ **8**

7- Stemming

$h_o = B$ **9**

2.5 THE EFFICTIVE FACTORS IN ROCK BLASTING EXPLOSIVE:

Explosives are used in the field under a variety of conditions. Today, the explosive reach very high technique like the loading techniques, they can by pumped or bulk loaded in holes, simplifying the operation but, at the same time, allowing the explosive to be directly affected by the environment of the borehole. The most important of explosives parameters and the factors which influence them are effect of charge diameter, effect of confinement, effect of particle size, effect of density, effect of initial temperature, effect of water

ROCK BLASTIBILITY:

Blastibility can be defined as the blasting characteristics of the rock mass subjected to a specific blast design, explosive characteristics and specified legislation constraints depending on site specific. In other words, blastibility indicates how ease to blast a rock mass under specified condition. According to Jimeno (1995), rocks are classified in four types, and the recommended selection criteria are resistant massive rocks, highly fissured rocks, rocks that form blocks and porous rocks.

DESIGN:

There are numerous theories extant concerning blast design and the general rules in this area can be concluded as: the weight of explosive increases as the square of the hole diameter, so considerably more energy can be concentrated in the toe of the hole. Stemming heights increase which often has the advantage that uncontrolled fly rock from the top of the blast is decreased. Fewer rows of holes are needed for the same tonnage which leads to better relief. It remains difficult, however, to translate these latter considerations into the field in a practical way. This is because different explosives with different energy outputs require different drill patterns for the same fragmentation.

GEOLOGY AND STRUCTURE:

It is fortunate for us, in rock fragmentation, that it is not yet necessary to become thoroughly familiar with this geo-scientific jargon. Rocks under loads leading to rupture show variable behavior. This natural variability in the behavior of rocks and rock masses, allows a certain generalization of the important characteristics required to successfully design a rock fragmentation system.

COSTING:

May be we can conclude the benefit of blasting in the following point:

- Increase shovel or loader capacity, reduce shovel or loader maintenance, increase truck throughput (reduce loading time), reduce truck maintenance, increase crusher capacity, reduce crusher maintenance, and decrease clean up costs to required. In addition there is technical procedure can reduce the over all cost represented in efficient explosives application to the least expensive and movement obtained is directly related to the amount of explosive.

2.6 FRAGMENTATION:

It is necessary to couple all the parameters, namely explosive and rock properties and surface blast design for an efficient blasting. Minor changes in the controllable parameters which are explosive type and surface blast design can have a major effect on the resultant fragmentation. Once the blast has been carried out, it is necessary to analyze the obtained results, as its interpretation will give hints for the successive modifications of the blast parameters for the following rounds.

2.7 FLY ROCK

Fly rock and failure to secure the blasting area dominate blasting-related accidents in mining, especially in surface mining. Blasting accidents in the mining industry tend to result in critical injuries or fatalities. Generally, fly rock is caused by a mismatch of the explosive energy with the geo-mechanical strength of the rock mass surrounding the explosive charge [20].

3. EXPREMENTAL WORK AND RESULTS

Experiments try to cover almost the main locations of the rock in Sudan in the different available conditions; this covering considers the various geology conditions in the Sudan which include the following sites:

1- Marble in Atbara 2.Granite in Kassala and Atbara and 3.Diorite in Alseleet.

These sites are almost covering all activities of rock supply in the Sudan except basalt rocks.

The plan of the practical is represented in the following steps:

1. Determine the stemming region through the different depth in individuals' holes for each type of explosive Figure 2 and observation for fly rock in all cases.
2. Collect the previous result in multi holes Figure 3 which included another test in pattern and delay system.
3. Registration of size of the products for the optimum spaces between holes.

3.1 MARBLE ROCK IN ATBARA SITE:

Atbara marble is the main raw material in the cement manufacturing in the country, and it occupies excellence classification in the worldwide standards related to its high percentage of calcium. The flowing experiments are done in this site:

Experiments with explosive ANFO type-1 and two diameters of drilling (89, 76 mm represent case 1 and 2). Experiments with explosive Ammonite starch mixture 3:2, 89 mm diameter of drilling (represents **case 3**). Variable depth of burial are used for different cases. Tables 1 to 3 represent the average results for these cases. The comparison of the three cases are given in Figures 4 and 5

3.2 GRANITE SITE IN KASSALA AND ATBARA:

Granite is one of the supply for building stone in Kassala, here for unavailable facility, we divide the test between Atbara and Kassala. These experiments (**case 4)** were carried out using different burial depth for one hole with the result of different experiment for the following entity:

Rock: granite Diameter of drilling: 32 mm Explosive: Ammonite.
Depth of burial: Variable
Results are represented in Table 4

3.3 DIORITE SITE IN ALSELEET:

Diorite is a one of the basic raw material which is used in the road and building construction as crushed stone. Here different methods were used for estimation and observation, these experiments (case **5**) consider the following entity:

Rock: diorite, Diameter of drilling: 102mm, Depth: variable, Explosive ANFO

Practical steps: Make some application from Langforce method, estimation & observation

Description (see Table 5)

Drilling design: Number of hole: 29,	Area (m): 10*32, Burden/space: 3/4
Bench height (m): 9-15	Holes inclination (degree): 0
Bench height: variable	Hole diameter: 102 mm
Stemming: 1.5 – 2 m	Type of explosive: ANFO

Results are represented in Table 6.

4. Discussion

Case1: The low density ANFO is used in this case to achieve optimum solution for the controlling of fly rock and fragmentation in 1m stemming. The design according to the crush zone is 1.5 m as a burden, and gets multi selections for the precaution blasting.

Case 2: The smaller diameter (76mm) with high density ANFO, result in wider width of crater, thus, bigger crush zone (from 3 to 5m) in the depth of 12m.

Case3 For the same diameter in the case1 and different type of explosive which is changed by using Ammonite and starch, 2:3 the crushing zone increases from 3 to 4m in the depth of 12m.

Case 4: In this case the crater method does not comply with base of blasting theory, because the fragmented cracks structure of the diorite in this site. On other hand it comply with the bench blasting theory of Langforce method.

Case 5: In the granite, small diameter used due to available facilities. The result of crater is different and didn't approach to clear solution in the fragmentation aspect. Howeve,r it arrived the safe point in the design for fly rock, it complies that it is intend to the ideal behavior for the given angle.

Generally Rock in Atbara and Kassala are dense and without appreciable cracks, so the explosive are fully acts ideally to the crushing of rocks. In contrast of this, in Alseleet, cracks directed explosive power to move rocks and this leads to ignore step one of the cratering theory.

Comparison show that Langforce work, can not be taken as standard for all cases and the limitation of this work is clearly seen in the cases of Atbara (marble) and Kassala (granite), while in Alseleet (diorite) duty of the explosive is limited to fragmentation analysis. This comments shows that weak analysis may lead to misleading results.

In contrast to some researchers, it is seen that small diameter of drilling may give larger cratering diameter in case of higher density of explosive this is approved by comparison between case 1 (drilling diameter 89mm), and case 2 (drilling diameter 76mm). These results is of great importance in the design and decreasing the cost of drilling.

ECONOMICAL ANALYSIS:

Cost comparison for before and after solution: The economical procedure deals with marble rock (Atbara) only as example of the gain of the study, so it shows the problem of the secondary blasting which is solved under the cratering concept. The economical study based to two practical cases in the same dimension, then we will take economical comparison between case1 and 2 assuming similar conditions. The cost before and after solutions are given in Figure 6 for the flowing specifications:

No. of holes: 40 holes. Drilling rate: 80 m/day. Explosive used ammonium nitrate. Initiation by electric delay detonator and detonating cord. The quantity of products: 1380 m^3

Cost comparison between case 1 (89 mm) and case 2 (76 mm): In this comparison it is clear that the main effective factor is represented in the drilling task, and may be with some negligible deferent. These results are very important since further steps might be taken to reduced the cost.

5. CONCLUSION

In the course of this study through practical result the following conclusion can be concluded:

1- The initial parameters in any analysis of rock blast are significant and leads in this work to select ammonite for granite, because the granite is massive nature, which needs firstly a shock to make cracks then needs gases pressure to move fragments, this is available in the ammonite specifications. Diorite in Alseleet does not need strong shock because the cracks already exist,. ANFO explosive is more suitable in Atbara.

2- The density and component of explosive is more effective factors than the diameter of drilling.

3- Increasing the density of ANFO over the limit of the died packing is more effective than the tries to mix ammonite to starch.

4- Langforce method is not applicable in Atbara and Kassala, but it is perfect in Alseleet site.
5- Economically, the effect of crater controlling in the stemming area is more effective than the density of explosive.

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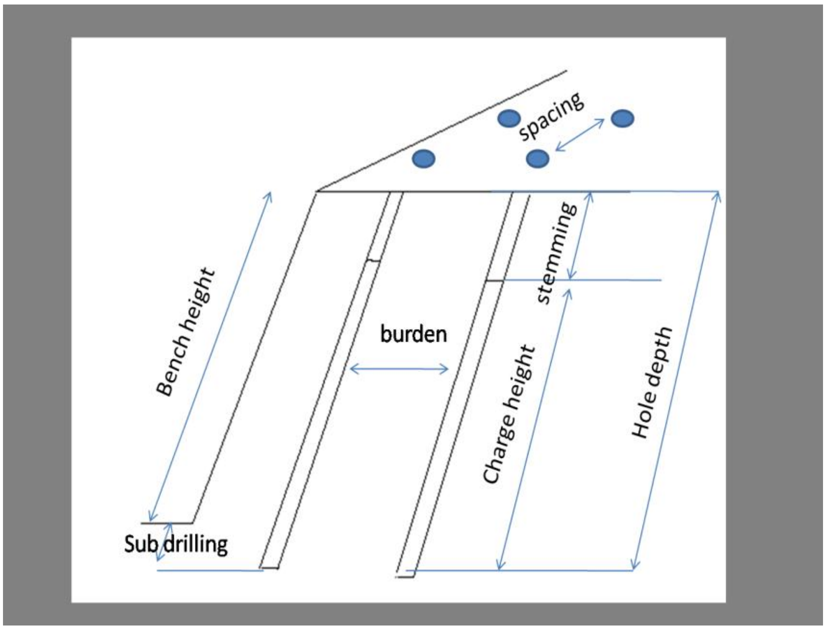

Figure 1: Langeforce method data.

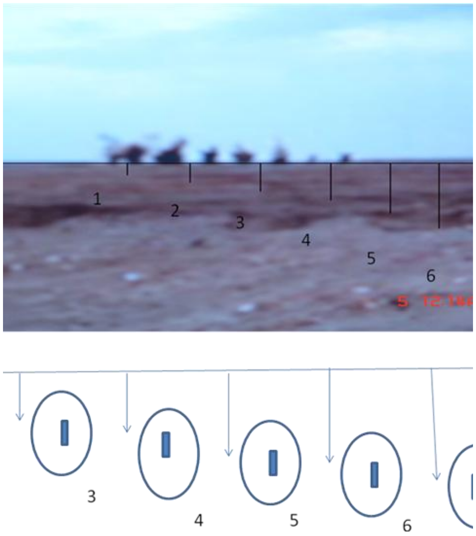

Figure 2: Different burial of depth and fly rock observation

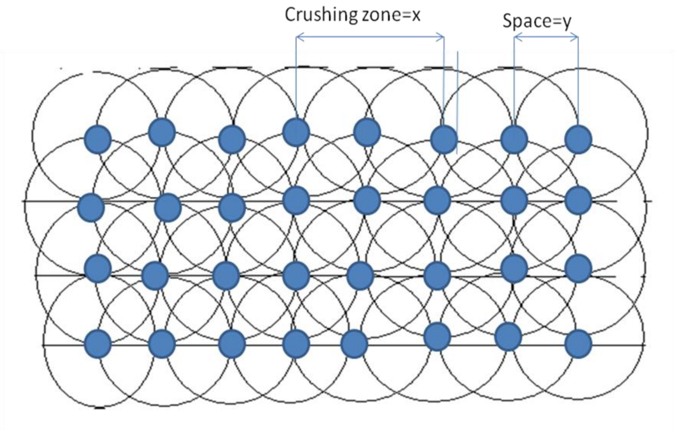

Figure 3: The assembly of crush zone

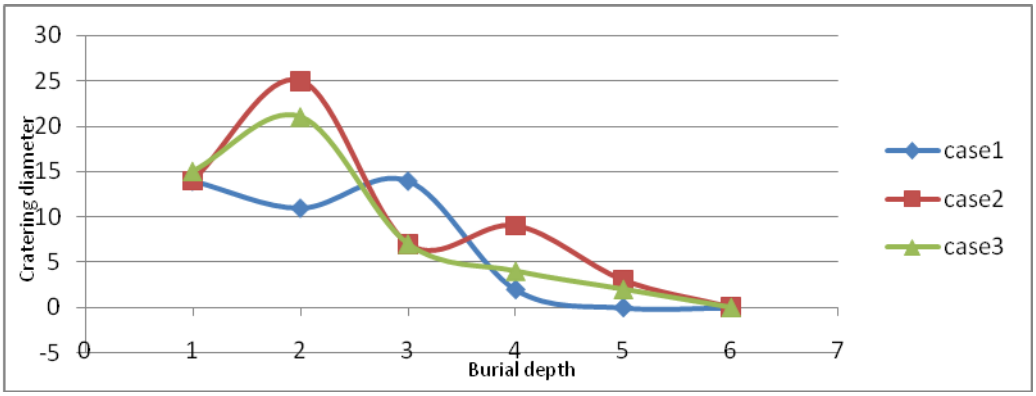

Figure 4: the comparison between cratering diameter in the marble in the various depths for different cases.

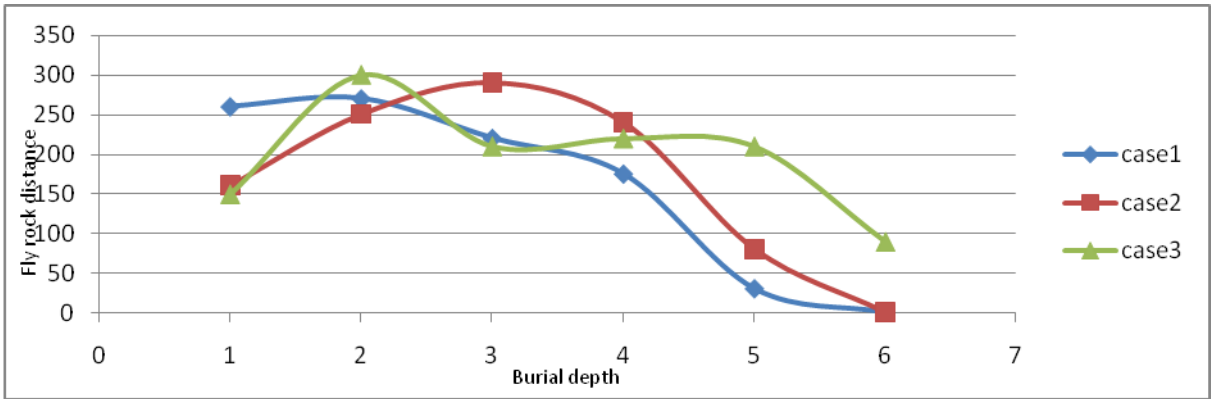

Figure 5: The comparison between the marble fly rock observations in the various depths for different cases.

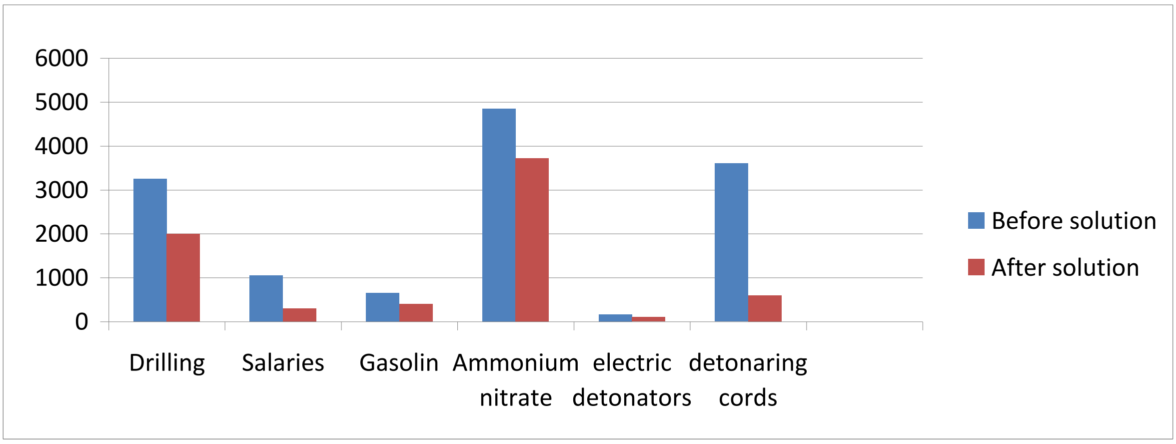

Figure 6: The comparison in cost between the effective factors for before and after solution (Cost in USD)

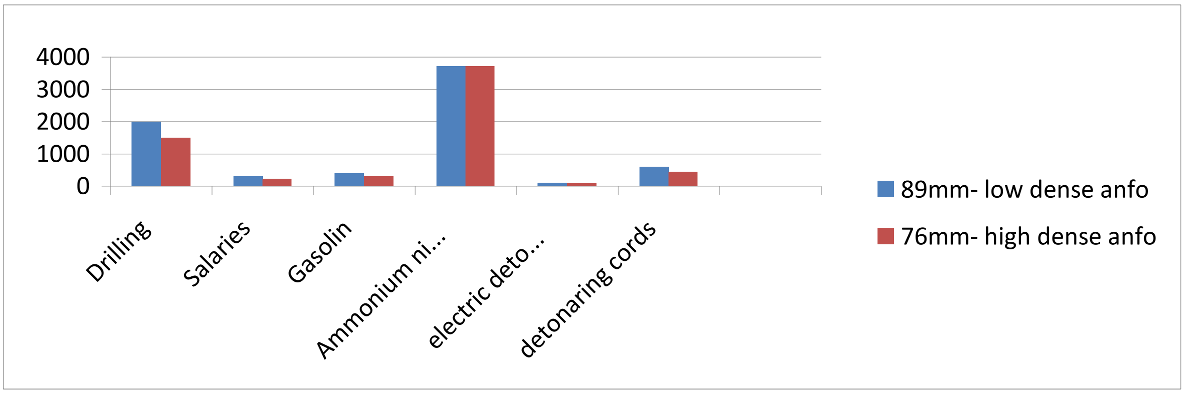

Figure 7: The comparison in cost between high and low dense ANFO (Cost in USD)

Table 1: Analysis data for Marble rock in Atbara site-case (1

Item	Data	Description	
Rock	Marble		
Explosive	Anf0 type -1		
Diameter	89 mm		
Type of stemming	Drilling products		
Stemming	Height	fly rock (m)	Fragmentation
	0 cm	14	Small
	50 cm	11	Optimum
	100 cm	14	Big
	150 cm	2	Very big
	200 cm	0	No fragment.
	250cm	0	No fragment.

Maximum Crater diameter	270 cm	In stemming 50 cm
Crush zone	3m	In bench height=12 m
Burden	1.5m	Minimum fragmentation (30cm)
Pattern design	straggler	
Delay time	25ms	Row by row

Table 2: Analysis data for Marble rock in Atbara site-case (2)

<table>
<tr><th>Item</th><th>Data</th><th>Description</th></tr>
<tr><td>Rock</td><td>Marble</td><td></td></tr>
<tr><td>Explosive</td><td>Anf0 type -2</td><td></td></tr>
<tr><td>Diameter</td><td>76 mm</td><td></td></tr>
<tr><td>Type of stemming</td><td>Drilling products</td><td></td></tr>
<tr><td>Stemming</td><td><table><tr><th>Height</th></tr><tr><td>0 cm</td></tr><tr><td>50 cm</td></tr><tr><td>100 cm</td></tr><tr><td>150 cm</td></tr><tr><td>200 cm</td></tr><tr><td>250cm</td></tr></table></td><td><table><tr><th>Flyrock (m)</th><th>Fragmentation</th></tr><tr><td>14</td><td>Small</td></tr><tr><td>25</td><td>Optimum</td></tr><tr><td>7</td><td>Big</td></tr><tr><td>9</td><td>Very big</td></tr><tr><td>3</td><td>Very big</td></tr><tr><td>0</td><td>No fragment.</td></tr></table></td></tr>
<tr><td>Maximum Crater diameter</td><td>290 cm</td><td>In stemming 100 cm</td></tr>
<tr><td>Crush zone</td><td>5m</td><td>In bench height=12 m</td></tr>
<tr><td>Burden</td><td>2.5m</td><td>*Minimum fragmentation (30cm)</td></tr>
<tr><td>Pattern design</td><td>Straggle</td><td></td></tr>
<tr><td>Delay time</td><td>25ms</td><td>Row by row</td></tr>
</table>

Table 3: Analysis data for Marble rock in Atbara site-case (3)

<table>
<tr><th>Item</th><th>Data</th><th>Description</th></tr>
<tr><td>Rock</td><td>Marble</td><td></td></tr>
<tr><td>Explosive</td><td>Ammonite-starch 2:3</td><td></td></tr>
<tr><td>Diameter</td><td>89 mm</td><td></td></tr>
<tr><td>Type of stemming</td><td>Drilling products</td><td></td></tr>
<tr><td>Stemming</td><td><table><tr><th>Height</th></tr><tr><td>0 cm</td></tr><tr><td>50 cm</td></tr><tr><td>100 cm</td></tr><tr><td>150 cm</td></tr><tr><td>200 cm</td></tr><tr><td>250cm</td></tr></table></td><td><table><tr><th>Flyrock(m)</th><th>Fragmentation</th></tr><tr><td>15</td><td>Small</td></tr><tr><td>21</td><td>Optimum</td></tr><tr><td>7</td><td>Big</td></tr><tr><td>4</td><td>Very big</td></tr><tr><td>2</td><td>Very big</td></tr><tr><td>0</td><td>No fragment.</td></tr></table></td></tr>
<tr><td>Maximum Crater diameter</td><td>300 cm</td><td>In stemming 50 cm</td></tr>
<tr><td>Crush zone</td><td>4m</td><td>In bench height=12 m</td></tr>
<tr><td>Burden</td><td>2m</td><td>*Minimum fragmentation (30cm)</td></tr>
<tr><td>Pattern design</td><td>Straggle</td><td></td></tr>
<tr><td>Delay time</td><td>25ms</td><td>Row by row</td></tr>
</table>

Table 4: Analysis data for Granite rock in Kassala site- case (4)

Item	Data	Description		
Rock	Granite			
Explosive	Ammonite			
Diameter	32 mm			
Type of stemming	Clay			
Stemming	Height	Flyrock(m)		Fragmentation
	0 cm	50		--------------
	10 cm	70		--------------
	20 cm	116		--------------
	30 cm	70		--------------
	40 cm	50		--------------
	50cm	10		--------------
Maximum Crater diameter	140 cm	In stemming 30 cm		
Crush zone	(140) no practical result but it is predicted	In bench height=3 m		
Burden	70cm	*Minimum fragmentation (20cm)		
Pattern design	Straggle			
Delay time	25ms	Row by row		

Table 5: The depth of holes in case (5)

No. row	Depth of holes (m)
1	9,5 9.5 12.5 12.5 12.5 12.5 15.5
2	9.5 12.5 12.5 12.5 15.5 15.5 18.5 18.5 18.5
3	9.5 12.5 12.5 12.5 12.5 15.5 15.5 18.5 18.5
4	9.5 9.5 12.5 12.5 12.5 12.5 15.5

Table 6: Analysis data of Diorite rock in Alseleet- case 5

Item	Data	Description
Rock	Diorite	
Explosive	ANFO	
Diameter	102 mm	
Type of stemming	Crushed stone	
Stemming (m)	1.5 – 2	
Burden(m)	3	In stemming 30 cm
Spacing (m)	4	In bench height=3 m
Pattern design	Straggle	
Delay time	25ms	Row by row
Fragmentation (cm)	20-30 cm	