Journal of Engineering Sciences
Assiut University
Faculty of Engineering
Vol. 48
No. 1
January 2020
PP. 54–64

DETERMINATION OF BENCH BLAST DESIGN PARAMETERS FOR LIMESTONE QUARRY AT GABLE OKHEIDER, AL AIN EL SUKHNA – WEST OF GULF OF SUEZ, EGYPT

Mostafa T. Mohamed [1], Mahran T [2] and Youssif Sh. Mohamed [3]

[1] *Mining and Metallurgical Eng. Dept., College of Eng. Assuit Univ.*
[2] *Geology. Geo. Dept., College of science. Sohag Univ.*
[3] *quarries and raw materials Dept., El - Sewedy cement Co.*

Received 14 October 2019; Accepted 8 December 2019

ABSTRACT

Bench design geometry parameters are considered the important issue of rock extraction. It directly has influences on rock extraction on all surface mines and quarries operation. This paper discuss the bench height calculation according to three important considerations; the stability of slope faces, the safety of the work place and the efficiency of the work place, besides the calculation of optimum working bench level width. Also, determination of optimum blasting bench parameters such as bore hole diameter and depth, spacing - burden ratio, sub-drilling depth, stemming length, stemming material type and size, decks type and decking length, type of explosive, column and bottom charge, powder Factor for limestone quarry at Al Ain El Sukhna – west of Gulf of Suez according to field trial tests.

1. Introduction

In surface mining drilling and blasting are the major unit operations and have a big effect on the materials fragmentation, safety and total production cost. Drilling and blasting cost in any quarry can reach 25% of the total production cost [1]. Bench height is important in the total quarry production cost, safety and ore dilution, so it must be assessed carefully [1]. The economical determination of bench height may vary with the machinery and equipments being used topography, capacity of drilling machine, environmental conditions, operation plans, etc. [2]. To maintain the cost at an optimum level, determining an economical bench height has to base on individual economic assessments of quarrying operation followed by the consolidation of individual assessments. Basic quarrying operations consist of drilling, blasting, loading and transportation. However, other parameters besides bench height, such as rock properties, blast hole diameter, bench geometry, type of explosives being used, etc. directly or indirectly influence the determination of the unit cost of the product. So optimization of bench height and other bench blast parameters leads to successful consequent operations such as loading and transportation from economical point of view.

2. Calculations of vertical height of bench

The height of bench calculation depends on some criteria such as cost, safety,

equipment availability, ore dilution and annual schedule of production [3].

Vertical height of bench and width of bench, can be calculated according to three considerations [4].

a- Stability of slope faces by using Tsykovich equation.

$$H_v = \frac{4C}{\gamma \, \text{Sin } 2\,\alpha} \quad (1)$$

Fellenius modified this formula to the following form.

$$H_v = 0.958\,\frac{4C}{\gamma} \quad (2)$$

According to Skololovsky, the limiting height of vertical face can be determined from the formula.

$$H_v = \frac{4\,c\cos\varphi}{\gamma(1-sine\,\varphi)} \quad (3)$$

Where; "φ" is angle of repose, degrees. Also Demen suggested the following formula.

$$H_v = \frac{\sigma c}{\gamma} \quad (4)$$

$$\sigma c = 2c\,\tan(45+\frac{\varphi}{2})$$

Where; "C" is cohesion, σc is Comperssive strength, "φ" is the angle of repose, α is slope angle of slip plane, degrees.

b-The safety of the work place.

The vertical height of bench should not be greater than 1.5 times the maximum digging height of the excavator or wheel loader for safety.

$$H_v \leq 1.5\,H_{dmax} \quad (5)$$

Where; H_{dmax} is the maximum digging height of the excavator.

c- Efficiency of the work place.

The height of the face can be determined by the following equation.

$$H_V = 0.7\,a\sqrt{\frac{\sin\alpha\,.\sin\beta}{k*\dot{\eta}(1+\dot{\eta})\sin(\beta-\alpha)}} \quad (6)$$

Where;

$$a = 0.8\,(R_d + R_L)$$

"a" is width of the broken down heap of material formed after blasting and "α" are slope angle of broken down material, deg, α ≈ 35 for limestone.

"β" is slope angle of the face, degree," K" is loosening factor of the face material values of "K" ranges from l.3 - l.9. "K" taken is 1.5 for limestone, "η'" is ratio of length of least resistance line of first row of blast holes to face height, usually equal to 0.55 - 0.70., " $\dot{\eta}$ "is ratio of distance between rows of blast holes to length of line of least resistance, usually equal to 0.75 - 0.85., "R_d" is digging radius of power shovel, m. and "R_L" is loading radius of power shovel , m.

3. Width of the quarry bench calculation

The width of working bench "W_L "can be calculated by the following equation.

$$W_L = X + C + T + Z + M + A \quad (7)$$

Where;" W_L" is Bench width, "C" is safety distance, "T" is trucks width, "Z" is safety distance between the trucks and loading machines (10 m – 20 m), "M "is loading machine width, "A "is burden and"X" is the distance between the face to the end of muck pile see figs. (1, 2), and can be calculating according to the following equation.

$$X = \frac{2\ A\ Hb\ ks}{H} - A\ m \quad (8)$$

Where; "A" is burden, "Hb" is vertical height of bench, "Ks" is swelling factor, "m" is 1 for hard rock, "m" is 1.5 for medium rock and "m" is 2 for soft rock.

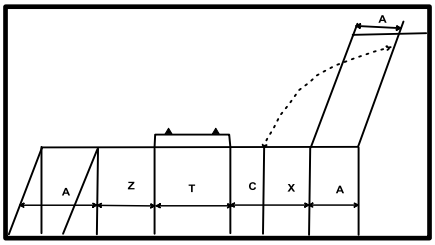

Fig. 1. Shows the bench width parts layout

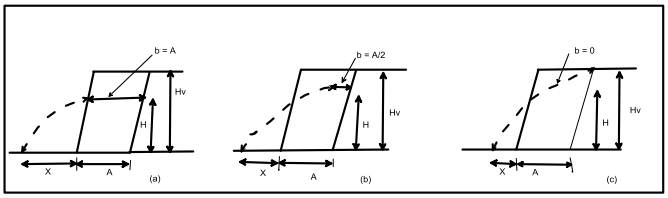

Fig. 2. Shows muck pile shape and width for (a,) for soft rock, (b) for medium rock and (c) for hard rock.

3. Determination of the Bench Blasting Parameters

The cost of surface mining production is Syndrome and identical with optimization of drilling and blasting. Loading, hauling and crushing costs decrease with increasing blasted rock fragmentation while drilling and blasting costs increase with increasing rock fragmentation [5]**.** The muck pile fragmentation size distribution is a function of the blast design parameters and the specific explosive charge of each hole [6]**.**

Cost decreased at an optimum fragmentation size in the surface mining operation and production [7, 8].The back bone of the blast results quality in surface mining is the efficiency and cost of drilling & blasting and subsequently mining unit operations such as loading, transportation and crushing operations [9].

Many formulae and methods used to calculate blasting parameters geometry (burden, spacing, and sub drilling) such as Role of thumbs, Ash, Langefors et al., and Jimeno et al. [10, 11].

Bench blasting design parameters are shown in Fig. (3), where; " D" is the diameter of blast bore hole (m), "H" is the height of bench (m), "B" the burden (m), "S" is the spacing (m). "S_D" is the sub drilling (m), "S_T"is the stemming length of blast bore hole (m), "L" is the length of blast hole (m), h_p is the column charge length (m), "h_b "is the bottom charge length (m). Other parameters that are taken into account in bench blasting calculations are; "I_p" is the column

charge concentration (kg/m),"I_b "is the bottom charge concentration (kg/m), "Q_p " is the column charge weight (kg)," Q b " is the bottom charge weight (kg), "Q e" is the total weight of explosive charge being used in a bore hole (kg),"q" is the powder factor (kg /m^3).

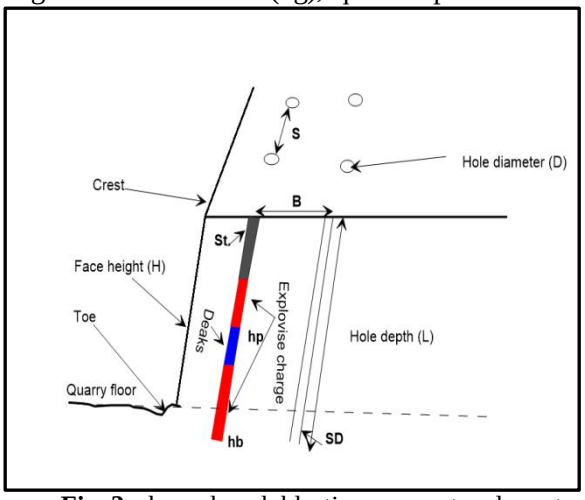

Fig. 3. shows bench blasting parameters layout

4. Calculation of bench blast parameters

The bench blast parameters can be calculated from the following equation according to rule of thumbs.

Burden "B "is the distance from a single row to the quarry bench face. It can be obtained from the following equation.

$$B = C_1 D \quad (9)$$

Where; "C_1" is constant and ranges between 25 - 40 and "D" is bore hole diameter.

Spacing "S" is the distance between blast holes parallel to the quarry face. Spacing is mainly a function of burden [12, 13]**.** Spacing is taken from the following equation.

$$S = C_2 B \quad (10)$$

Where; "C_2" is constant ranges between 1 to 1.5.

Stemming is a specific material placed on top of explosive in the drilling bore hole. The main goal of stemming is to close the hole and go back with it to original state as much as possible in order to confine the explosion gases to reduce the blasting noise. The stemming material could be water, drill cutting, sand, mud or crushed rock. Stemming distance " S_T "is depend upon bore hole diameter or burden as following.

$$S_T = (0.7\text{-}1.0)\ B \quad (11)$$

Sub drilling is the borehole extends length below the quarry floor or the bench height and can be calculated from the following equation.

$$S_D = (0.2\text{-}\ 0.5)\ B \quad (12)$$

5. Ash method for bench blast parameters calculation

A mathematical equations for bench blast geometry parameters developed by Ash [14] and used also by many authors such as [15- 18].

The burden "B" is arithmetically estimated from:

$$B = K_B D \quad (13)$$

Where; K_B = 22 in case of ANFO for rock density less than 2.7 g/m^3, and 30 for rock density more than 2.7 g/m^3, but in case of high explosive K_B = 27 for rock density less than 2.7 g/m$^{3.}$ and 25 for rock density more than 2.7 g/m^3.

Spacing "S "can calculated from the following equation.

$$S = K_s B \quad (14)$$

Where; "K_s" is constant and it range between 1& 2.

Spacing to Burden Ratio.

Spacing and burden ratio can vary between 1 and 2, when its less than 1 is not recommended [19, 20] because it causes premature division of the bore holes and early release of gaseous pressure and losing the contribution of gaseous energy in rock fragmentation. Spacing and burden ration more than 2 is also not recommended because it may result in incomplete breakage between the holes and poor fragmentation.

Sub drilling depth "S_D" can calculated from the following equation.

$$S_D = (0.2\text{-}0.5)B \quad (15)$$

The common stemming can be calculated as follow.

$$S_T = (0.5\text{-}1.3)B \quad (16)$$

Stemming can be achieved when it equal 0.7 to 1.2 times the burden [21, 22]. The optimum stemming material size is 0 .05- 0. 08 times the bore hole diameter [16]**.**

The spacing "S" can be calculated from the following equation.

$$S = \frac{H+7\,B}{8} \quad (17)$$

Decks is separating two or more charges within a hole, fired at different delays. The purpose of decks is to reduce loading explosives in weak zones which is may be mud, cracks or voids. The stemming length between decks equal 6 times the bore hole diameter. The plaster stemming technique is better than the drill cuttings stemming technique because of increased locking provisions inside the hole and better utilization of blast explosive energy in the rock [23].

The bottom charge height should be equal to.

$$h_b = 1.3B \quad (18)$$

The bottom bore hole charge concentration is equal.

$$I_b = (D^2/1000)\,(P/1.25) \quad (19)$$

The bottom charge total quantity can be calculated from the following equation.

$$Q_b = h_b\, I_b \quad (20)$$

The column charge height can be calculated from the following equation.

$$h_p = H - h_b - (S_T + \text{Decks}) \quad (21)$$

The column charge total quantity is given as:

$$Q_p = h_p I_p \quad (22)$$

Total bore hole explosive charge being used (kg) is given as.

$$Q_e = Q_p + Q_b \quad (24)$$

Type of explosive depends upon the rock properties of the geologic formation, water-filled boreholes, bore hole diameter and blasting cost.

The powder factor is a relationship between the quantities of broken rocks and how much explosive is used to break it. The most common powder factor in surface mining is 0. 3 - 0. 6 (kg/m3) but it can vary from 0.15 to 1 .5 (kg/m3) [24].

The calculation of powder factor can be derived from the following equation depending upon the rock density [25]**.**

$$q = K + B\ p \quad (25)$$

Where;"q" is powder factor (kg/m^3), "K", "B" are constants it's for limestone equal 0.733 and 0.400 respectively and "p" is the rock density (gm/cc). The influence of joints must be taken in consideration as introducing a correction factor as appears in the following empirical equation.

$$q_0 = \frac{q}{j} \quad (26)$$

Where; "q_0" is corrected powder factor by kg/m^3."q" is powder factor calculated from the previous equation and "j" is the correction factor depending on the block size.

Powder factor in surface mining can also calculated by knowing both of bottom and column bore hole charges from the following equation.

$$q = \frac{Q\ \text{total}}{B * H * S} \quad (29)$$

Where; "Q_{total}" is total bore hole charge."B" is the burden distance."H" is the bench height "S" is the spacing distance.

Cost of explosive materials per cubic meter according to the blasting contactor of Egypt can be calculate by using the following formula.

$$\text{Cost} = \frac{Q\ total}{qc} * F \quad (30)$$

Where; q_c is fixed powder factor taken as 0.3 (kg/m^3), F is the fixed powder factor unit cost taken as 9 L.E according to explosive supplying company.

6. Laboratory and field works

6.1. Rock geotechnical tests

Four limestone samples collected from the limestone of Gabel Okheider to determine the mechanical properties of the rock. The results are summarized in table (1).

Table 1.
Mechanical test results of Okheider limestone samples.

Rock Properties	Average
Compressive Strength (kg/cm^2).	226.7
Shear Stress (kg/cm^2).	39.625
Water Absorption (%).	6.09
Dry Density (g/cm^3).	1.95
Wet Density (g/cm^3).	2.04

7. Field data collection and measurements

To calculate the bench height and width we need some field measurements carried at the quarry area near the new quarry these data shown in the following table (2).

Table 2.
Field data collection and measurements.

Items	Values
Muck Pile Length (m).	35
Angle of Repose (degree).	35
Loader 980H Height (m).	6
Loading Trucks Length (m).	12.5

8. Trial blast at Okheider limestone quarry for bench blasting parameters determination

Three trial blasts were performed at limestone quarry at Ain Sukhna area to select the best blasting parameters according to the field observations for the rock fragmentation of the blasted muck piles.

Trial 1.

The test has been carried with burden 4 (m), spacing 8 (m), stemming 5 (m), sub drilling 3 (m), 2 decks with 1(5 m), length, the mass of bottom charge is 40(kg) of dynamite and the mass of column charge is 260 (kg), of ANFO and with powder factor 234 (g/m^3).This trial test gave a good results of fragmentations so it was suitable for crushers without using the secondary blasting and breaking by jack hammer as it seen in Fig.(4).

Fig. 4. Blasting trial -1 during charging and muck pile fragmentation

Trial 2.

This blasting test has been carried out with burden 7.5 (m) put as a test by the authors, spacing 9 (m), stemming 5.5 (m), sub drilling 2 (m), two decks about 2 (m), length, with mass of bottom charge 22 (kg), of dynamite, mass of column charge 328 (kg), of ANFO

and with powder factor 128 (g/m^3). This trial test gave bad fragmentations as it gave a large numbers of blocks more than two meters. This leads to use secondary blasting or breaking by jack hammer gave rise of cost.as seen in Fig. (5).

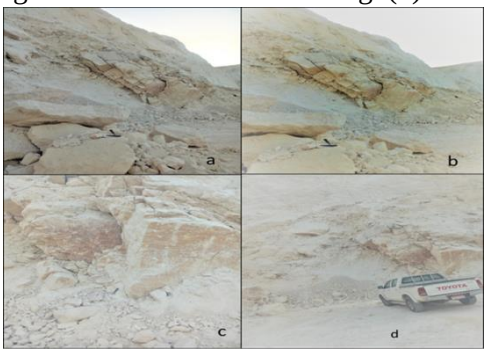

Fig. 5. Blasting trial -2 during charging and muck pile fragmentation

Trial 3.

This blasting test has been carried out with burden 4.5 (m), spacing 8 (m), stemming 5 (m), sub drilling 2.5 m. with two decks about 2 (m), with mass of bottom charge 12 (kg), of dynamite, mass of column charge 340 (kg), of ANFO and with powder factor 305 (g/m^3), the fragmentation are extremely fine as it seen in Fig. (6). This leads to clogging in crusher. Fig. (7), explains the charge methods for the test trails.

Fig. 6. Blasting trial -3 during charging and muck pile fragmentation

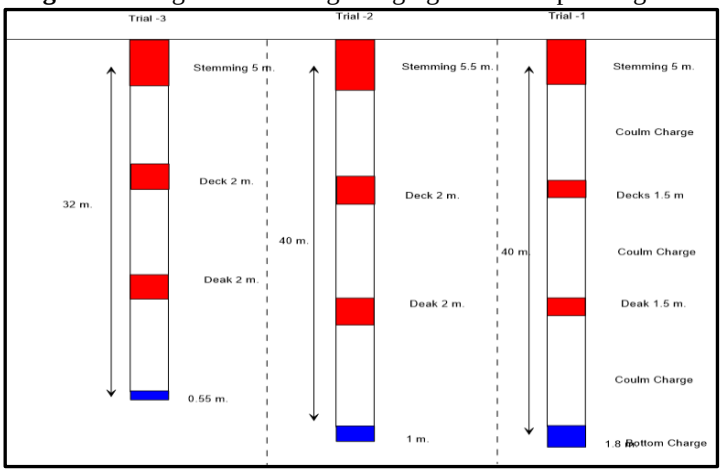

Fig.7. Explains the charge methods for the test trails.

9. Results

The bench height of Okheider limestone quarry due to stability of the face slope equal 115 m. this means that quarry face can reach 115 m. from the point of view of face stability.

The height of bench according to safety of working place equal 9.75 m.

The bench height calculation of Okheider limestone quarry is 16.8 m. after calculation from equation no.6 due to the efficiency of working place.

The bench width at the studied quarry equals 39.9 m. when using available Caterpillar wheel loader 980H type.

The aim of this study is to reach to a good blasting fragmentation of muck pile suitable for crusher feeding with low cost so the powder factor Calculation using rock density equation is too high and will increase the total blasting cost for Okheider limestone.

Calculation of the blasting design parameters using Rule of thumb and Ash approaches produced the results in Table (4). These results from the two different methods of determination processes were very different from each other.

Determination of bench blasting parameters of three blasting trial field tests results are presented in Table (4), the trials have been carried out at different bench heights and with different powder factors.

Table 4.

summary of blasting design parameters results of empirical blasting equations and three trial blasting tests.

Parameter s	Rule of Thumbs Methods	Ash Methods	Trial no. 1	Trial no. 2	Trial no. 3
Bench Height (m).	40	40	40	40	32
Bore Hole Diameter (mm).	152	152	152	152	152
Burden (m).	4.6	3.3	4	7.5	4.5
Spacing (m).	5.7	5	8	9	8
Spacing / Burden Ratio.	1.2	1.5	2	1.2	1.78
Sub Drilling (m).	1.4	1	3	2	2.5
Bore Hole Depth (m).	41.4	41	43	42	34.5
Stemming (m).	6.8	3	5	5.5	5
Stemming Materials Size (mm).	0.065-2	0.065-2	0.065 - 2	0.065 - 2	0.065 - 2
Depth and number of Decking (m *no.).	-	-	1.5*2	2*2	2*2
Charge Length (m).	34.5	38	35	32.5	24.5
Type of Explosive.	G.Dyt & ANFO	G.Dyt & ANFO	G. Dyt. & ANFO	G. Dyt. & ANFO	G. Dyt. & ANFO
Bottom charge length (m).	6	4.3	1.8	1	0.55
Blast Hole Bottom charge weight (kg).	109	80.3	40	22	12
Blast Hole Column charge length (m).	27.2	32.7	33.2	31.5	22.95
Blast Hole Column Charge weight (kg).	503	604	280	328	340
Blast Hole Total charge /hole (kg).	612	684.3	320	350	352
Rock Volume. (m^3)/Hole.	1048.8	660	1280	2700	1152
Powder Factor (g/m^3).	580	1004	250	128	305
Fragmentations.	Unsuitable	Unsuitable	Suitable	Unsuitable	Unsuitable
Cost (L.E/m^3).	17.74	30.12	7.5	3.84	9.15

10. Conclusion

According to the vertical height of bench calculations, the bench height of Okheider limestone quarry equals to 115 m, is save but it is not applicable due to expected difficult drilling process and poor fragmentation. The vertical height of benches 16.8 m. and 9.75

m, have problem in the total quarry production and cost. Okheider limestone quarry will be designed to produce around 5-6 million tons annually. So from the economic point of view the selected height of bench is taken between 30-40 m, to verify the target of quarry production, the determining width of bench is taken as 40 m.

According to field observations (fragmentation and cost calculations) the author found that Rule of thumbs and Ash bench blast parameters calculation methods are not suitable due to very high cost per cubic meter. The author has found that trial-1test has the best values of bench blast design parameters for the limestone quarry at Gable Okheider due to low cost and good fragmentations. So, due to the variation of rock formation properties of Okheider limestone quarry compared to the formation in the selected empirical equations, some modifications have to make to these equations. The authors suggest that these relationships become as the follow.

$$B = 0.026\ D$$

$$B = H/10$$

$$S = 2\ B$$

$$S_T = 1.2\ B$$

$$S_D = 0.75\ B$$

Where; "B" is the burden in m,"H" is the bench height in m, and" D "is hole diameter in mm.

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ايجاد معاملات تصميم مصطبة التفجير لمحجر الحجر الجيري بجبل اخيضر بمنطقه العين السخنه غرب خليج السويس

العناصر الهندسية لتصميم مصطبة التفجير تعتبر من اهم المراحل لاستخراج الصخور. هذه العناصر لها تأثير مباشر علي استخراج الصخر في جميع المناجم السطحية و المحاجر. هذا البحث يناقش حساب ارتفاع مصطبة التفجير طبقا لثلاث اعتبارات مهمه هي: اتزان وجهات مصطبة التفجير, امان منطقة العمل و كفاءة منطقة العمل بجانب حساب عرض مصطبة العمل المثالية. أيضًا إيجاد عناصر تصميم مصطبة التفجير المثالي مثل قطر فتحة البئر وعمقها، المسافة البينة بين ابار التفجير ,الحمل , النسبة بين المسافة البينة و الحمل, طول الحفر الإضافي ، طول عمق الردم، نوع وحجم مادة الردم، طول الردم المتقطع داخل البئر، نوع المتفجرة ، حساب شحنة العمود وشحنة القاع، حساب معدلات استهلاك المتفجرات لكل متر مكعب من الحجر الجيري مستخرج بناء علي تجارب حقلية تم اجراءها في محجر الحجر الجيري بمنطقة العين السخنة غرب خليج السويس مصر.