PROCEEDINGS
OF THE 12th CONFERENCE ON EXPLOSIVES & BLASTING TECHNIQUE

PROCEEDINGS
OF THE TWELFTH CONFERENCE ON EXPLOSIVES AND BLASTING TECHNIQUE

EDITED BY

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FORWARD

Commercial explosives are used to benefit mankind. The purpose of the conference on explosives and blasting technique is to provide a convenient source of information in this area of rapidly changing technology. The new Mini-Symposium on Explosives and Blasting Research presented with the annual conference further broadens the perspective of the Society and its membership. The technical papers presented have been carefully selected to present state of the art information. This book has been refereed by a panel of experts selected from universities, industry and government. Many of the procedures described in this book are new and unique. It is incumbent on the reader to determine for himself whether the techniques herein described are suitable for his particular application. The book is sold without warranty expressed or implied.

Membership in the S.E.E. is increasing continually, as well as the conference (over 500), and symposium attendance (over 150). At the end of 1985 membership reached 1614 including 59 corporates. The membershp is representative of 58 countries and 49 of the states in the USA.

This continued steady growth indicates the need for this type of an organization and its objectives. We are grateful for the ongoing support of the Board of Directors, Officers and general membership. We welcome your input and with our combined efforts, plan for an even larger conference in 1987 in Miami, Florida, February 1-6.

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"A CONCENTRATED VIEW OF DRILLING AND BLASTING IN SOUTH FLORIDA"

by

Ron Fish, Miramar Rock
Cherokee Stone Div. of Davison Minerals
Herman Bowman, Retired Broward County Agent
Randy Tolliver, Ensign-Bickford

ABSTRACT

Drilling and blasting in open pits is very unique in Southern Florida. Crushed limestone, the state's most abundant mineral resource, is retrieved from the bottoms of huge open pits that are completely inundated with fresh water. It is this industry that makes southern Florida the fastest growing area in the United States.

INTRODUCTION

Yes, there is rock in Southern Florida. Twenty-five million years ago a relatively young algae reef dam was trapped, forming an oolitic limestone or fossiliferous limestone deposit (Ref. 1). The Southeast United States was once covered by a shallow sea which possessed bank reefs which rarely reached the surface. The platform, the Floridian foundation, rose and fell with the impact of millions of years of erosion taking its toll. During the submergence of the platform in the Tertiary period, reefs were formed over a considerable part of the area. The platform in the last million years was impacted actually by the glacial and interglacial times. The Pleistocene reefs which grew during these changes formed rock 100 feet thick littered with erosional and depositional features (i.e. oolite (sand) deposits and mud pockets). In the last glacial age, while the sea level was low, a platform was cut into the land. As the ice caps settled for the last time, the platform was again flooded. This platform is the base for the coral reefs growing off the Florida keys. Earth movements independent of glacial actions caused portions of the Pleistocene reefs to form the keys from Miami to the Dry Tortugas (Ref. 2).

CRUSHING OPERATION

Broward and Dade County represent a high percentage of crushed stone used in the state of Florida. The stone is crushed typically by roller crushers. The material is then screened according to the type of material for which it will be used. Miramar Rock, a crushing outfit, runs the crushing plant during the night hours from 9:00 pm until 6:00 am. Commercial trucks are lined up in the morning as early as 6:30 to start their hauling.

PIT EQUIPMENT

The common equipment used in stripping, excavation, loading and hauling are draglines, front end loaders, and end dump rock trucks, respectively. The limestone reserve requires uncovering peat (a very lightweight black soil) and vegetation with dragline and/or front end loader. Stripping is normally done during the dry season between November and April. The water table will fluctuate between 3 and 4 feet, depending on the season and the location. During the wet season significant amounts of fill material (shot rock) are brought into the freshly excavated area to build a pad. The pad serves two purposes: 1) allows drill to operate out of the water and 2) provides a platform for equipment to run across and operate on. The shot rock is bailed out of the water/pit and stacked adjacent to the lake and appears like bare mountain ranges from a distance. The stacks of shot material are allowed to dry before it is loaded and hauled to the crusher.

DRILLING

Drilling the pits provides an exceptional challenge. Since the rock formation is stratified, pockets of sand and voids (caverns) are very prominent here. The average depth of drill holes hangs around 55 feet deep. With the inconsistency the formation offers, blasthole tubes have become an absolute necessity in the rock pits. The tubes provide a medium to which deep holes can be reliably loaded and provide better insurance that the explosives are coupled. The tube loading process is very simple. The inner steel is brought up through the kelly bar, then, the cardboard tube is slid down the kelly bar and a block of wood is placed between the bit on the inner steel and the cardboard lip to protect the cardboard. The tube has a steel meshed screen on the bottom end for the purpose of containing the explosive. The diameter of the tubes range within 3-1/2", 4", and 4-1/2". The bit on the kelly bar is 7-1/4" in diameter. The burden and spacing can be anything on the front row but 16' x 16' or 16' x 18' is commonly drilled.

J. E. Childers, D & B, Inc. has been the dominant drilling service in south Florida for 10 years. In the past 13 years Jim Childers has drilled and blasted over 100 million cubic yards.

BLASTING

Two blasting services that are covered in this presentation offer down hole service as well as shot service. This has become a prevalent practice for the explosive usage in the southern Florida open pits. Thermex provides a packaged explosive and Ireco provides a pumped explosive. Both shot services use the Nonel® Primadet® system. Richard Cooper, the head blaster for Thermex, claims that the Nonel® Primadet® system provides them with an accurate delay system that is simple to load and particularly easy to snap in. The MS Units have helped speed up loading due to a faster sinking time. The blasthole tubes provide a protective barrier for cap leads. The packaged product is shipped from Brooksville, Florida, by trailer on pallets. This is referred to as palletization. The blasting truck is driven between the rows of holes and personnel load the holes right from the pallets on the open bed. After the shot is loaded, the blasting truck leaves for another operation while the licensed blaster snaps in the surface delays. Richard Cooper prefers to run the 42ms Nonel® Trunkline Delays along the back row of holes and the 17ms Nonel® Trunkline Delays along the echelon (Diagram 1) The intention here is to blast against sold. Breakage in the Cherokee Crushed Rock Pit has improved tremendously.

Ireco pumps explosives into the borehole as the loading hose is drawn out of the blasthole. The pump trucks are backed up to the front row between holes and pull directly forward while loading holes on each side of the truck. Clay Fowler, Ireco's South Florida Manager, prefers to use Nonel® Primadets® because of the ease of loading, especially the MS units. Clay feels that their shot service is successful due to the fact that they can get the holes loaded quickly and surface delays snapped in and get out quickly, minimizing down time for the pit operation. Ireco shoots the largest shots pulled in south Florida at Miramar Rock, which is located next to Ireco's plant. Ron Fish, Miramar Rock's manager, believes the more holes that are shot at one time improves the fragmentation tremendously and reduces the complaints because a fewer number of shots are pulled per year.

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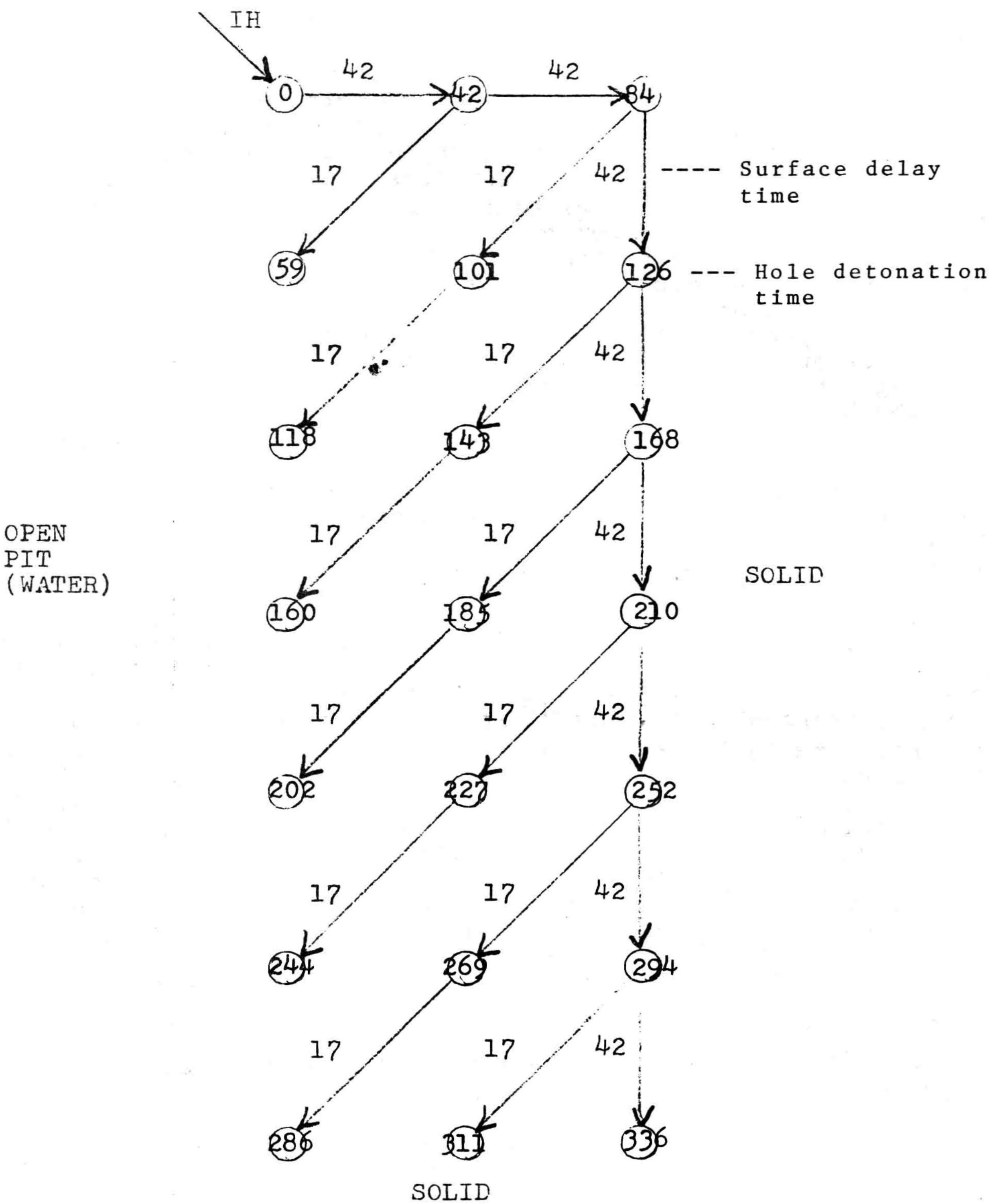
SHOT MATERIAL



BLASTING FACTORS INFLUENCING THE CHOICE OF BLASTHOLE SIZE FOR QUARRYING

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ABSTRACT

Hole size affects many factors which directly influence fragmentation in the muckpile and hence, the cost effectiveness of the entire operation. These factors include production capability, explosives and accessories efficiency and usage and drilling accuracy. In addition, hole size should be chosen to suit the geological conditions.

The paper concludes that the optimum hole size is generally the largest that can be used commensurate with production and environmental considerations.

INTRODUCTION

It perhaps seems inappropriate for an explosives man to talk about drilling. The author has no pretensions to being an authority on drilling, but hole size has an important bearing on blasting parameters. It is hoped that this paper will help to identify the area where the drilling and blasting disciplines overlap, and focus attention to this area when equipment is purchased.

Good and efficient blasting requires that:

(a) *sufficient energy is provided, in the right form, for the job in hand.* This requires an understanding of the relationship between hole size and explosives energy requirements.

(b) *all of that energy is released usefully.* Hole diameter affects both the explosive characteristics and the possibility of interruptions in the explosives column.

(c) *the explosives are correctly distributed through the rock mass.* Hole diameter affects the accuracy of drilling and also the geometry of the blasting.

(d) *on detonation, flyrock, ground vibration and airblast are kept within specified limits.* Control of these factors is directly related to hole diameter.

(e) *there should be minimal cost and maximum safety.* Cheaper and less sensitive explosives can be used in larger diameter holes.

The choice of blasthole diameter therefore has a major influence on blasting design, quite apart from the obvious fact that larger holes produce more rock per metre drilled.

The important linking factors between explosives and drilling can be considered under the following headings, (not in order of importance):

1. Explosives selection.
2. Blasting accessory usage.
3. Blasting geometry.
4. Drilling accuracy.
5. Production requirements.
6. Geology.

1. EXPLOSIVES SELECTION

i. Performance

The cap sensitive explosives normally supplied in cartridged form are designed to deliver full energy in small diameter blastholes. There is a cost penalty for this ability as high performance products for larger diameter blastholes are often less sophisticated, and hence, cheaper. If explosives, that are formulated for large diameter blastholes, are used in intermediate diameter holes then full performance is unlikely to be realised.

ANFO is a particularly good and relevant example. It is used effectively in hole diameters as small as 25mm but, as indicated in Figure 1, only reaches maximum performance (as measured by detonation velocity) in holes exceeding 127mm (5inches) in diameter.

Explosives that have a high detonation pressure break hard rocks easier. This detonation pressure (P) is given by the equation:

$$P = \rho \frac{D^2}{4}$$

where P = detonation pressure (GPa)

ρ = explosives density (g/cc)

D = detonation velocity (km/s)

Hence, ANFO is much more effective on a mass for mass basis when used in larger holes as its increased velocity of detonation gives a higher detonation pressure.

ii. Practical considerations.

The evolution of explosives from cartridged to pourable and pumpable forms was accelerated by the advent of large diameter blastholes. Cartridged explosives have a number of disadvantages over pourable kinds. (See Table 1). In the interests of economy, productivity, safety and convenience it is well worthwhile choosing a hole size large enough to permit the efficient use of poured or pumped explosives. Holes smaller than 100mm do not really lend themselves to pumping as the rate of column rise is too rapid for good control and excessive time is spent in manipulating the loading system rather than delivering explosive.

If poured or pumped explosives can be used, the hole size has an important bearing on the scale of equipment required for delivery into blastholes. Figure 2 illustrates the rate of column rise in different hole diameters for certain delivery rates of ANFO.

2. BLASTING ACCESSORY USAGE

Each blasthole, regardless of diameter, requires its own initiation system in addition to the timing system used on the surface. The cost of the initiation system is therefore directly related to the number of holes. With larger holes, not only can accessory costs be reduced, but having less holes permits limited delay ranges to be used for larger blasts. It also becomes more economical to adopt the sophisticated initiation systems which offer maximum control over blasting results.

A typical example in South Africa:

A quarrying operation with 64mm holes on a 1,8 x 2,2m pattern is constricted in using electric millisecond detonators, owing to:

(a) A limited range of twenty delays being available.

(b) Limitations in respect of exploder capabilities.

As a result, blasts exceeding 100 holes require a degree of faith and ingenuity in implementation. In-the-hole initiation with NONEL® Benchmasters is desirable, but is reluctantly undertaken owing to the slightly increased cost and effort of providing two units in a hole which will only produce 40 - 50 Bank Cubic Metres (B.C.M.)

The situation is greatly improved if the quarry changes over to, for example, 127mm holes on a 3 x 3,8m pattern, thereby producing 115 to 145 B.C.M. per hole. The same production rate now requires 60% less holes, which means that:

(a) In-the-hole initiation systems cost almost 70% less per B.C.M. broken.

(b) Layout of the delay system is simpler.

NONEL® is the registered trademark of Nitro Nobel AB of Gyttorp, Sweden.

3. BLASTING GEOMETRY

i. Pattern size and powder factors.

AECI's "Kuz-Ram" blasting model quantifies the effects of blasting lay-out on fragmentation. We have used it to forecast how hole size affects the size of average fragmentation in the muckpile.

Larger holes enable wider drilling patterns to be drilled but higher powder factors must also be adopted to preserve the same fragmentation. This is a manifestation of the less uniform distribution of explosives throughout the rock mass.

Table 2 shows typical drilling patterns, powder factors and drilling efficiencies for a range of hole diameters assuming a fixed explosive type and average fragment size in a homogeneous rock.

Figure 3 gives an example of how the average fragment size from blasting may increase with hole size if the technical powder factor (i.e. calculated using the explosives mass above grade level) and all other variables remain constant.

It is evident that as hole size increases, the benefit in terms of the reduced drilling cost per B.C.M. broken becomes offset by:

(a) Higher powder factor required.

(b) Reduced hole utilisation owing to the necessary increase in stemming.

(c) Less uniform fragmentation distribution. (Even if the average fragment size is the same as for smaller holes, the oversize boulders would tend to be larger).

Thus, as would be expected, the *scale of operations* are a critical factor when deciding on hole size.

ii. Bench height.

For a given explosive in homogeneous rock the hole diameter directly governs the burden on a hole and hence, its *length of stemming* and *sub-drill.* However, both these latter factors are largely independent of face height.

As the breaking is generally poor in the vicinity of the un-charged stemming area of a hole, it follows that the bench height should be maximised relative to the stemming length in order to reduce the percentage of oversize in the muckpile.

Where shorter benches are necessary, i.e. for mineral grade control purposes, then smaller diameter blastholes are recommended requiring less stemming and therefore, resulting in a minimum of oversize. This is illustrated in Figure 4.

Sub-drilling is unproductive but essential for clean breaking. In low benches this can account for a high proportion of the drill metres. Smaller diameter holes with reduced burden require less sub-drill and are therefore, more efficient. Figure 5 shows that the efficiency difference between small and intermediate diameter holes is significant in low benches.

4. DRILLING ACCURACY

Uniform blasting results are obtained by drilling on a fixed burden and spacing. Inaccurate drilling causes variations of the individual burdens and spacings resulting in inconsistent breaking. This problem generally manifests itself at the toe of the hole where the deviation from the planned position is at its maximum and breaking conditions are at their toughest. (See Figure 6).

To quantify the effect of drilling accuracy on fragmentation, Figure 7 gives an example as simulated by our computer model. It shows the predicted deterioration in fragmentation as the standard deviation of the toe of the hole from its planned position increases from 0 to 0,8m for 64mm and 127mm holes drilled on the pattern, given in Table 2. The reason for the minimal effect on the 127mm holes is that a fixed deviation has a smaller relative effect on the wider drilling pattern. Thus the fragmentation penalty for poor drilling accuracy is worse for smaller holes.

Figure 8 illustrates some common causes of drilling errors, most of which can be avoided by sound practice. It is true however, that larger diameter holes are more accurate as the use of down-the-hole (DTH) drills, or rotary bits with roller stabilisers, eliminates deflection errors over normal bench heights.

5. PRODUCTION REQUIREMENTS

i. Drilling capability.

The blasthole diameter greatly affects the volume of rock that can be blasted per drill unit per day. An approximate equation for calculating the drill capability for an ANFO operation is given by:

$$E = PN/\left[\frac{2000K}{D} \times \left(\frac{1}{D} + \frac{1}{125H}\right)\right]^{-1}$$

where E = B.C.M. per day per drill.

D = hole diameter mm.

P = penetration rate m/h (including move and set-up time).

N = drill utilisation per day h.

K = powder factor kg/cu.m. (Normally varies between 0,3 for soft rock types with high penetration rates and 1,0 for hard rock types with low penetration rates).

Using this equation we have plotted curves in Figure 9 to give a trend of expected production rates in Bank Cubic Metres (equivalent) drilled per day for varying blasthole diameters in different rock conditions. We have assumed that penetration rates do not vary with hole size, and are higher in softer rock types. It is evident that larger blasthole diameters prove to be progressively more attractive in terms of productivity when rock breaking conditions are easier.

When selecting an optimum hole size, it is usually best to choose a hole size which requires at least two or three drills on site (in case of break-downs) and to arrange the blasting schedule such that several rows of holes are blasted at a time.

In general, in the interest of preserving good fragmentation, it is advisable to increase the Powder Factor as hole size increases. Blasting specialists can advise on the necessity and extent of such an increase.

ii. Multi-row blasting.

Poor fragmentation, toes, flyrock and noise are blasting problems that can be related to the front row of holes.

Oversize can arise from slabs of jointed rock on the face, often loosened by backbreak from previous shots. These slabs slide out without further breakage as the front holes fire. In subsequent rows the rock is tightly packed and the hole timing is quick enough to prevent adverse movement taking place. Consequently, in-situ blocks are fragmented by normal explosive attrition mechanisms.

The frequently ragged nature of the face results in uneven burdening on the front holes, and it is this that leads to flyrock, excessive noise and toes. By resorting to multi-row blasting with up to seven rows, but commonly three or four, the contribution of the front row is diluted, and all these problems are minimised.

If the hole diameter is excessive for the required production, relatively few holes are needed for each blast. This is likely to result in single or double row blasting with the associated problems. It is therefore better to keep hole size small enough to fit in with the bench width and production requirements.

iii. Environmental effects.

In built-up areas, flyrock, airblast and ground vibration levels must be strictly controlled. Depending on geological conditions and actual distances to private property, blasthole diameter should not be so great that the risk of overstepping limits is high. It is true that in order to aleviate this problem more sophisticated techniques can be employed, such as multi-in-hole delays or deck charges. It is worth noting that in Europe and the United States, much larger blasthole diameters are used than are found in similar conditions to that experienced by the author in Southern Africa. This should change in the future with an expected increase in trained Blasting Supervisors in the African sub-continent.

6. GEOLOGY

i. Hole closure.

In weathered ground formations or where there is a predominance of slip planes, a primary cause of poor blasting results is the absence of explosive due to the blasthole being blocked at some point. It is particularly frustrating to have the expense and effort of drilling a hole and then to not be able to charge it. The majority of hole blockages occur either on completion of the drilling or during charging operations. They are caused either by loose fragments from the blasthole sidewall or carelessness in dislodging surface stones into the hole. The frequency of losing holes in this way is very much reduced as the blasthole diameter increases beyond 100mm.

ii. Joint spacings and tightness.

The manner in which explosives energy is transmitted and radial crack development around a blasthole is greatly affected by pre-existing joints. Crack growth is least affected when the joints are tight. However, the rock breaking process can be severely impaired if the joints are open as there is preferential breaking within the joint formed in-situ blocks intersected by each blasthole.

The situation is most detrimental to a quarry operation when the joint spacing corresponds to the boulder dimension that is considered to be over-size. In such cases, it is advisable to drill on a small pattern (and by implication hole diameter) in order to minimise the percentage of over-size by intersecting as many joint formed in-situ boulders as possible. (See Figure 10).

iii. Surface capping.

Normally the surface is already broken up through weathering or the shattered ground of explosives in the sub-drill from the previous bench. Occasionally however, blasting takes place with a competent capping rock. To make things worse this can sometimes be underlain by rocks with pronounced horizontal bedding or even a layer of loose fill. Under such conditions larger diameter holes are unadvisable as long un-charged collars must be left to avoid flyrock. Failure to charge the capping results in over-size problems. Under such conditions smaller holes which only require 1 - 2m of stemming provide a simple solution.

CONCLUSION

A combination of theoretical analysis and practical experience indicates that there is a suitable range of hole diameters for each blasting operation, the general rule being to identify the priorities applying and use these as a basis for selecting size. This is not a trivial procedure; computer analysis and discussion with experienced personnel in geology, drilling, blasting and loading equipment is necessary to avoid mis-matching of equipment.

Table 3 summarises some of the main advantages of larger and smaller holes. As a rule, within a particular range of applicable sizes, the larger ones are more beneficial.

ACKNOWLEDGEMENTS

Many thanks to my colleague, Claude Cunningham (Technical Services Manager - AECI Explosives), for collating the information required for this paper.

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APPENDIX 1

Calculation of Production from Blasthole Drills using ANFO Explosive.

1. Powder Factor (K) $= \dfrac{\text{Explosive Mass per Hole}}{\text{Volume Broken per Hole}} = \dfrac{L \times Mc}{B \times S \times H}$ ------------- Equation (i)

where
B = Burden, m.
S = Spacing, m.
L = Charge Length, m.
Mc = Column charge per metre of hole (kg).
H = Bench Height.
K = Powder Factor, kg/m^3.

For the purpose of this calculation the following approximations can be made:

(a) B = S
(b) Mc = $0{,}000785D^2\rho$
where D = hole diameter
ρ = effective in-hole explosive density - ANFO is the most common explosive and therefore, by way of example, we will substitute its usual in-hole density of 0,8g/cc in (b).
i.e. Mc = $0{,}000785\ D^2 \times 0{,}8$.
= $0{,}000628\ D^2$ kg/m.

(c) L/H varies commonly between 0,5 for very large blastholes on low benches and 0,9 for smaller holes and high benches.

Assume that L/H = 0,8 for most applications.

2. Equation (i) can therefore be modified to:

K = $H \times 0{,}8 \times 0{,}000628D^2/(B^2 \times H)$

i.e. $B^2 = 0{,}0005D^2/K$

3. Metres actually drilled per hole depends on angle of hole and sub-drill.

As a rough estimate, let hole depth = Bench height + 8 hole diameters
= H + 8D/1000 metres.

4. Cubic metres per metre drilled
$= (BxSxH)/(H + 8D/1000)$
$= B^2H/(H + 8D/1000)$
$= 0{,}0005D^2H/[Kx(H + 8D/1000)]$
$= [(2000K/D^2H) \times (H + 8D/1000)]^{-1}$
$$= \left[\frac{2000K}{D} \times \left(\frac{1}{D} + \frac{1}{125H}\right)\right]^{-1}$$

5. Let overall drilling rate be P m/hr per unit.
Hours drilled per day = N.
Then total metres per day = PN.

6. Total cubic metres produced per day per drill = cubic metres broken per metre drilled x metres drilled per day
$$= PN/\left[\frac{2000K}{D} \times \left(\frac{1}{D} + \frac{1}{125H}\right)\right]$$

Assumptions:
(a) L/H = 0,8
(b) Subdrilling = 8 hole diameters
(c) Explosive = ANFO

TABLE 1

RELATIVE MERITS OF PACKAGED VERSUS UNPACKAGED EXPLOSIVES

FACTOR	CARTRIDGED EXPLOSIVES	PUMPED/POURED EXPLOSIVES
Coupling	Diameter less than hole: poor utilization of hole and reduced explosives performance owing to the "channel effect"	Maximum use of hole volume
Storage	Expensive and restricted storage in magazines	Low cost bulk storage
Loading	Manual operation: slow and labour intensive in larger holes	High loading rates and productivity in larger blastholes
Cost	Highest price bracket applies	Lower pricing
Control of load per hole	Excellent control of charge per hole and length of stemming	Problems can arise with explosive running into cavities and with controlling length of column
Transport	Restrictions on amount carried and type of transport	Relatively little restriction especially for on-site mixed products
Security	Risks during transportation and storage	Minimal security risk as the explosive is manufactured on-site

TABLE 2

DRILLING/BLASTING ESTIMATES FOR CONSTANT FRAGMENTATION IN MEDIUM HARD ROCK WITH DIFFERENT DRILL DIAMETERS

Blast Hole Size, mm	**64**	**76**	**104**	**127**	**200**
B x S, m	2 x 2,5	2,3 x 2,8	2,9 x 3,5	3,3 x 4,1	4,5 x 5,5
Reduced Burden, m($\sqrt{B \times S}$)	2,24	2,54	3,19	3,68	5,0
Stemming, m	1,3	1,5	2,1	2,6	5,0
Sub-drill,m	0,7	0,7	1,0	1,1	1,5
Overall Powder Factor, kg/m^3	**0,49**	**0,52**	**0,61**	**0,66**	**0,82**
kg per hole	34,5	47,9	87,6	126,6	286,4
Percentage of hole charged	96	94	92	89	81
B.C.M./m drilled	**4,76**	**6,17**	**9,56**	**12,6**	**22,5**
No. holes for 10 000 B.C.M.	143	111	70	53	29
Metres drilled	2102	1632	1050	800	450

Fixed Parameters

Explosive	: ANFO, Density 0,8g/cc
Bench Height	: 14m
Drilling accuracy	: SD = 0,4m
Mean Fragmentation	: 36cm