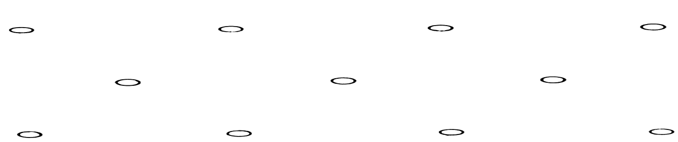
Chapter 8
BLAST DESIGN

HOLE PATTERNS

Hole array is the arrangement of blastholes (both in plan and section). The basic blasthole arrays are single-row, square, or rectangular and staggered arrays. Irregular arrays are also used to take in irregular areas at the edge of a regular array. The term SPACING denotes the lateral distance on centers between holes in a row. The BURDEN is the distance from a single row to the face of the excavation, or between rows in the usual case where rows are fired in sequence.

(Figure 8-1) Square or rectangular pattern

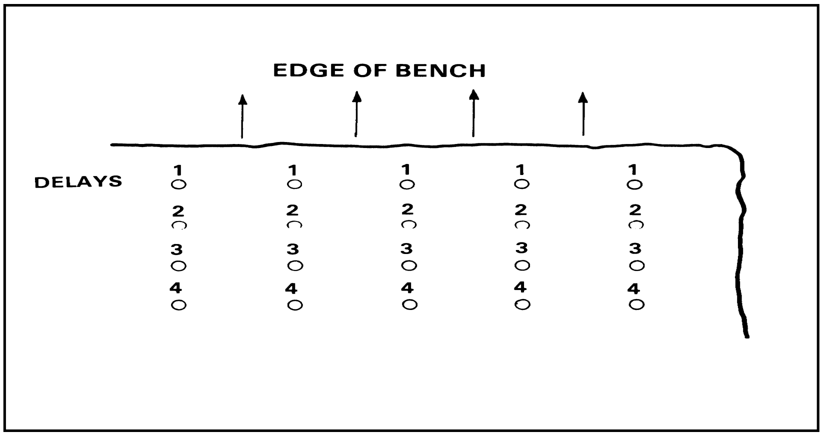


(Figure 8-2) Staggered pattern

(Figure 8-3) Sing

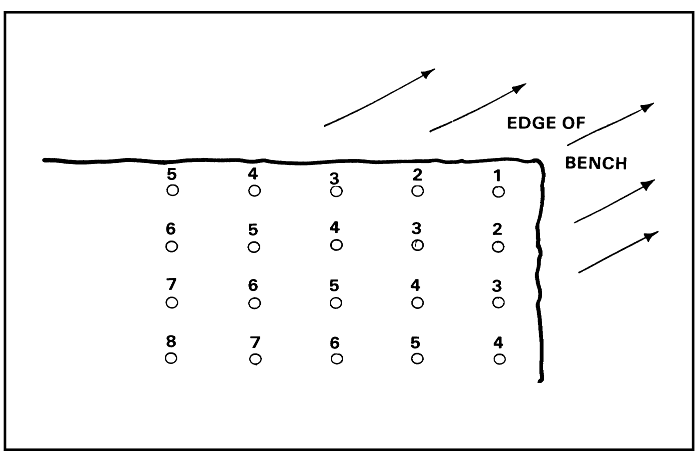
DELAY PATTERNS

Delay patterns, and varying the hole array to fit natural excavation topography, allow for more efficient use of the explosive energy in the blast. Benches may be designed and carried forth with more than one face so that simple blasting patterns can be used to remove the rock. In the illustration that follows (Figure 8-4) shows a typical bench cut with two free faces and fired with one delay per row.



(Figure 8-4) Typical bench cut with two free faces and fired with one delay per row.

Figure 8-5 indicates that the direction of throw of the blasted rock can be controlled by varying the delay pattern. The rock will move forward normally to the rows of holes. If the holes are fired in oblique rows as in Figure 8-5, the rock mass would be thrown to the right during blasting.



(Figure 8-5) Direction of throw of blasted rock.

POWDER FACTOR

Calculating Powder Factors

The POWDER FACTOR is a relationship between how much rock is broken and how much explosive is used to break it. It can serve a variety of purposes, such as an indicator of how hard the rock is, or the cost of the explosives needed, or even as a guide to planning a shot. Powder factor can be expressed as a quantity of rock broken by a unit weight of explosives. Or, alternatively, it can be the amount of explosives required to break a unit measure of rock. Since rock is usually measured in pounds, there are several possible combinations that can express the powder factor.

Powder Factor = Tons of rock (or cubic yards) per pounds of explosive.

Normal range = 4 to 7
Shallow holes = 1 to 2
External loads = .3

$$\frac{\text{Tons of Rock}}{\text{lbs of Explosives}} = \text{Powder Factor}$$

The higher the powder factor, the lighter the load.
Lower powder factor means more explosives.
Example:

$$\frac{\text{1.5 tons}}{\text{.25lbs}} = \text{PF of 6}$$

BURDEN-SPACING CALCULATION

From Powder Factor of 1 lb./c.y.

1. Determine borehole size.
2. Determine stemming: 24 x borehole diameter; Divide by 12 to get the number of feet.
3. Determine subdrilling: 1/3 x stemming.
4. Determine amount of hole to be loaded. Use bench height plus subdrilling minus stemming.
5. From Table 4 of Blaster's Guide, determine pounds/foot of explosive.
6. Determine total load. Multiply amount of hole to be loaded (Step #4) by the pounds per foot of explosives (Step #5).
7. Divide the total load (Step #6) by the bench height. This will equal the number of cubic yards that can be broken at 1 lb/cy.
8. Determine approximate square pattern from Table 1 of Blaster's Guide, or multiply the number ob
9. Adjust to a rectangular pattern of the same total cubic yards.
10. Adjust stemming and subdrilling amounts.

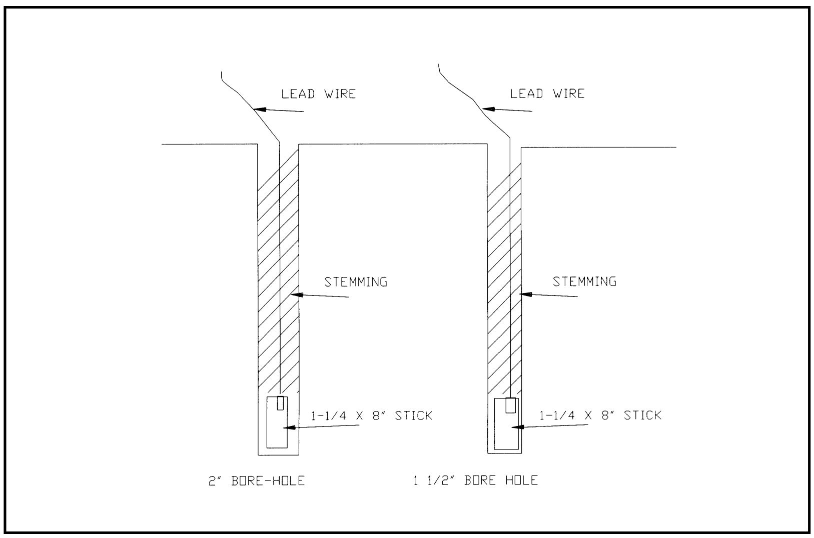
NOTE: For powder factor other than 1 lb/cy: divide the resultant number of cubic yards obtained in Step #7 by the powder factor desired.

Formula for determination of resultant height of water when using cartridges to "dry up" the borehole.

H = Resultant height of water in feet
Dh = Borehole diameter in inches
W = Water in hole in feet
Dc = Cartridge diameter in inches

$$H = \frac{Dh^2 \times W}{Dh^2 - Dc^2}$$

BOREHOLE COUPLING



(Figure 8-6) Borehole coupling.

AIR: THE ENEMY OF AN EXPLOSIVE

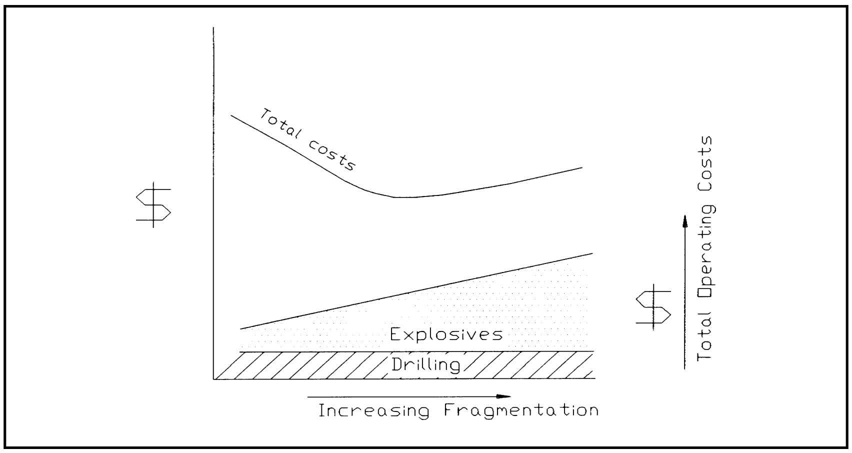
Borehole coupling is critical to good fragmentation of rock. The borehole should never exceed the diameter of the explosive by more than one-half inch. The air gap around an explosive charge absorbs the shock energy and results in poor fragmentation.

The explosive column illustrated in Figure 8-6 on the right will produce the best fragmentation.

EXPLOSIVES ECONOMICS

The economic analysis of the use of explosives is an important part of blasting operations in mining and construction. Explosives are energy, and the efficient use of this energy is a major factor in keeping rock blasting costs under control. High-energy explosives enhance fragmentation, which ultimately produces a positive effect on production costs. The degree of fragmentation or movement obtained is directly related to the amount of operation. This relationship is illustrated in Figure 8-7.

explosive energy applied to the surrounding rock. Analysis of the cost of explosives requires that the effects of explosive energy be placed into proper perspective within the entire drilling, blasting, handling and processing operation. This relationship is illustrated in Figure 8-7.



(Figure 8-7) Analysis of efficient blast design..

Efficient blast designs combined with the proper choice of explosive can produce better fragmentation with associated lower operating costs compared to blast designs and explosives used under adverse conditions. As a result, the efficient use of explosives, along with the proper borehole diameter selection, are the keys to a successful blasting program.

COST OF ENERGY

The only way to evaluate accurately the cost of explosives, is to examine the effects of blasting and to determine the optimum degree of fragmentation. In most cases, the productivity rate is influenced by the degree of fragmentation. To obtain well-fragmented rock by blasting, explosive energy must be well distributed throughout the rock. To be effective in rock blasting, this energy must be applied at the proper millisecond delay interval to allow for optimum rock movement.

The type and cost of explosives will vary from one operation to another, dependent upon many conditions. The geologic formation, such as hard seams, cap rock, hard bottom, or large toes, dictate the use of high-energy explosives. Water-filled boreholes require the use of water-resistant products at a premium cost. The cost of a product upgrade to cope with wet conditions is an obvious input. Other variables, such as the size of mucking equipment and drilling equipment, fragmentation tolerance, and production demands, will also influence the choice of explosives.

Although a significant recurrent expense, the cost of explosives is usually only a small percentage of the total costs encountered in breaking, moving, and processing rock and ore. The small difference in the cost of a higher energy explosive is insignificant compared to a decrease in production caused by insufficient fragmentation.

ENERGY FACTORS

The *energy factor* describes the energy distribution within a given unit of rock. Energy distribution within a shot is measured by the energy factor, which compares the explosive energy to a quantity of rock broken. The explosive energy distribution within the entire blast is then evaluated along with its resulting fragmentation and its effect on operating costs. Blasting analysis next becomes a function of the energy factor, explosives cost, fragmentation results, and subsequent production.

Proper energy distribution is important in obtaining the desired fragmentation and movement of the bottom or toe portion of the shot. Energy distribution becomes an important factor when wet holes are encountered, as cartridged explosive products must be smaller than the borehole diameter to allow for easier loading. The resulting decrease in the diameter of the explosives column, reduces the amount of explosive energy within the borehole. The blaster must use higher energy explosives to balance the lost energy.

Necessary explosive energy adjustments at the borehole can be made to compensate for excessive toe, hard bottom, or cap rock. In addition, higher energy explosives can be substituted for lower energy explosives to increase the energy distribution within the rock, thereby increasing fragmentation. However, if fragmentation was satisfactory before the introduction of additional explosive energy, the improved energy distribution within the shot will allow for an expansion of the drilling pattern, with resultant decrease in overall drilling costs.

Improved production rates and consequent cost reduction in digging, hauling, crushing, or moving rock are the major benefits obtained from the efficient application of explosive energy. There are other benefits from better fragmentation, such as reduced secondary blasting, reduced power consumption at the crusher, and less wear and maintenance on equipment with less down time.

Explosive efficiency is the ratio of the amount of energy released to the calculated thermochemical energy. Emulsions are highly efficient explosives, due primarily to their microscopic particle size. In contrast, explosives with varying particle size, such as ANFO or water gels, will not have a uniform burning rate, and therefore, will not be as efficient. Studies comparing the calculated thermochemical energy to the measured energy by the underwater bubble energy technique, have shown that the emulsions released 93 percent of the calculated thermochemical energy. Water gels with varying particle sizes achieved only 55 to 70 percent of their calculated thermochemical energy. The explosive efficiencies of ANFO, and particularly of high-density ANFO, range from 50 to 80 percent of their calculated energies. As a result, emulsion explosives are not only thermochemically efficient, but are cost-efficient as well.

Drilling and Loading Considerations

While the relative rock hardness has an effect both on drilling and explosives performance, environmental factors exert their influence as well. Among the factors to consider in studying drilling costs are: bit costs, labor, fuel consumption, penetration rates, maintenance, machine life, and machine cost. For example, severe water conditions in the borehole will require more expensive explosives resulting in a higher energy cost than would be experienced with a maximum use of ANFO. In semiarid regions of the southwest United States, drilling costs may represent as much as 80 percent of the total drilling and blasting costs, mainly because of utilization of the lower cost explosive. By contrast, in the northeastern United States, hard rock formations exist in a relatively wet environment, where the explosives costs can be as much as 70 percent of the total drilling and blasting expense.

Blasting vibrations and air blast concerns may have a direct influence on which blasting program the operator may select. Because of such constraints, the blaster may need to impose limits on quantity of explosives per delay, which relates directly to hole sizes and depths.

Borehole diameter and the depth of the hole must always be evaluated in any cost analysis including explosives. Relatively expensive explosives required for efficient performance in a three-inch diameter hole may be unrealistic from a cost standpoint for a six-inch diameter hole. Though drilling cost in a six-inch hole in similar material will be at least twice that for the smaller hole, less expensive explosives usually can be utilized in the larger hole with no sacrifice in explosive performance.

When contemplating a change in drill hole size, compare the area of influence associated with the respective holes. Whereas a three-inch diameter hole has an area of 7.07 square inches, the six-inch diameter hole is four times greater, with an area of 28.27 square inches. The same relationship exists with respect to energy of similar explosives.

Different blasting conditions may indicate both a change in bench designs as well as explosive selection. An increase in hole size, along with the same explosive, may still fall short of providing the desired results. Such situations may also require the adoption of a higher velocity, more energetic explosive. Where drilling and blasting conditions are both severe, the operator should use premium explosives, at least in the bottom one third of the drill hole. Clearing the toe, and therefore contributing to a smoother floor, is a major asset to improve overall economy because of the favorable impact on excavation and haulage costs.

BLAST DESIGN

Rules of Thumb for Blast Design

Nearly every occupation or discipline has its own particular "rules of thumb," and blasting is no exception. These are rules, not law. The following is a set of guidelines based on practical experience and technical information. Blasting projects vary so much that there can be no set of rules to cover every possible contingency. Be sure that the advantage gained from breaking the rule is greater than the penalty to be paid for that violation.

RULE 1: The detonation velocity of the explosive should match, as closely as possible, the sonic velocity of the rock to be blasted.

The rock's sonic velocity (VSO) is a reliable indicator of its structural integrity and resistance to fragmentation. As the detonation velocity of the explosive (VOD) increases toward the rock's VSO, fragment size decreases and uniformity of fragmentation increases. If large fragments are desired from a blast, such as for ballast rock, then the VOD should be considerably lower than the rock VSO. Obviously, if the VOD is too low relative to the rock VSO, the result will be huge irregular blocks or chunks.

If detonation proceeds at the same, or close to the same, speed as the transmission of sound waves, the resulting breakage will be optimum, more uniform, and equal along the entire explosive column. Maximum borehole spacings and burdens can then be used.

There is no value in using an explosive that has a VOD greatly in excess of the VSO of the rock, since there is little or no improvement in fragmentation above the VSO.

When selecting an explosive to match up the VSO of a rock mass, there is no need to match the VOD of the explosive to within a few feet per second of the VSO of the rock. Variance in the velocities below 10 percent either way should be more than sufficient.

RULE 2: Generally select the most dense explosive possible, consistent with water, loading conditions, and desired results.

The more dense the explosive, the more of it that can be placed in a borehole of a given size. Explosive density is expressed as its weight in g/cc, and since water has a density of 1.0 g/cc, it is obvious that an explosive with a density less than 1.0 will float, whereas, if the density is more than 1.0, it will sink. Less obvious is that the higher the explosive density, the greater the weight of explosive material (potential energy) that can be placed within the borehole.

For example: A single borehole 3.5 inches in diameter and 33 feet deep will hold, if stemmed 8 feet with 127.5 pounds of an explosive with a density of 1.25 g/cc. If an explosive with the same VOD, but with a density of 1.4 g/cc, was used in that borehole, the amount of explosive which can be loaded in the hole increases to 142.5 lbs.

If a powder factor of one pound per cubic yard is required, the spacing and burden for the explosive with the density of 1.4 will be greater than that for the explosive with a density of 1.25.

RULE 3: Select explosives according to the characteristics of the rock formation to be blasted.

Although Rule 1 states that explosives should be selected on the basis of matching VOD to VSO, and Rule 2 stresses high density, there are many instances where the structural characteristics of the rock formation allow, or even require, use of lower density, lower velocity explosives (i.e., ANFO).

In those instances where the planes of separation in the rock are smaller than the degree of fragmentation required, the rock can often be blasted by merely "bumping" the rock with explosives.

A close study of the breakage planes in the rock mass will indicate whether or not a lower velocity and density explosive should be used. This subjective determination hinges upon knowledge of the rock and experience with varying rock formations.

RULE 4 - When using slurry or water gel explosives, always determine the critical temperature below which the explosive will fail to reliably detonate.

Almost all slurry explosives have a critical temperature below which they may not detonate, or may not sustain detonation in elongated columns. This critical temperature is usually noted in the technical data sheets supplied by the manufacturer or distributor. Under no circumstances should the explosive be used when the temperature of the explosive at time of loading is below that critical temperature.

In addition to the temperature of the explosive itself, consider the temperature of water that may be in the borehole, since slurry products are often used in wet boreholes. In many parts of the United States, particularly in the northern states during winter months, it is not unusual for water temperature in the boreholes to reach below the critical temperature of the explosive.

Guidelines for Blasting Geometry

RULE 1: The distance between holes (spacing) should not be greater than one-half the depth of the borehole.

When the effect of a blast is simulated on graph paper using an assumed or idealized angle of breakage of 90 degrees, the diagrams indicate that in each instance where the distance between holes in a row is greater than one-half the depth of the hole, the angles of breakage intersect so far above the bottom of the holes that the primary relief for each hole is to the surface. This causes both a great deal of vertical throw and a very uneven bottom. The greater the disparity between depth and spacing, the more pronounced the effect will be, to the point where the angles of breakage intersect above the surface of the shot.

RULE 2: In any blast where there is hole-for-hole delay, the spacing to burden relationship should be seven to five.

Several investigations about the science of rock mechanics have suggested that the optimum spacing to burden relationship should be 2:1, with the burden equal to one-half the spacing. Field experience shows that this relationship has two drawbacks. First, the blaster may assume that this relationship will apply when there is no delay system at work, when in fact, the optimum spacing to burden relationship in all instantaneous blasts should be 1:1 to ensure equal distribution of explosives in the blast. Second, if an instantaneous blast is fired with a spacing to burden relationship of 2:1, the back wall of the blasted area will, in most cases, be "sawtoothed."

When delays are used, particularly when there is hole-for-hole and row-for-row delay, with no two holes firing on the same period, the angle of breakage approaches the idealized ratio of 2:1. The slight addition of burden avoids the possibility of "blowout," or violent throw from relieved burdens during the shifting of burden from one hole to another.

RULE 3: Stemming should be equal to the burden.

The purpose of stemming, it has long been assumed, is to return the borehole to its original condition as much as possible in order to reduce noise, and possibly rifling at the top portion of the hole. Stemming also serves to confine and maximize efficient use of the explosive's energy.

If the explosive detonation process takes place up the borehole, the surface of the rock above the stemming is as much a free face (assuming there is a free face) as the free face that is parallel to the boreholes. If the stemming is greater than the burden, the rock at the top of the borehole will have less cracking from reflection and refraction of compressive and tensile waves. Then stemming should equal burden, and be of such material as to return the rock close to its original condition. Drill fines, tamped into the hole are ideal.

RULE 4: Subdrill (if necessary) should be between .3 and .5 of spacing.

Some investigators state that subdrill should be equal to .3 of burden. This is true in instances where spacing and burden are equal, such as with instantaneous blasts. It will also work when there is row-for-row delay. In blasts where the delay system is both row-for-row and hole-for-hole, however, the subdrill should be determined by the largest dimension, which is the spacing. An average subdrill of .4 of spacing is best to use for planning purposes.