Chapter 19

BLAST DESIGN

Introduction

This chapter is an introduction to blasting techniques based primarily on the *Explosives and Blasting Procedures Manual* (Dick et al., 1987) and the *Blaster's Handbook* (E.I. du Pont de Nemours & Co., Inc., 1978). Blast design is not a precise science. Because of widely varying properties of rock, geologic structure, and explosives, design of a blasting program requires field testing. Tradeoffs frequently must be made when designing the best blast for a given geologic situation. This chapter provides the fundamental concepts of blast design. These concepts are useful as a first approximation for blast design and also in troubleshooting the cause of a bad blast. Field testing is the best tool to refine individual blast designs.

Throughout the blast design process, two overriding principles must be kept in mind:

(1) Explosives function best when there is a free face approximately parallel to the explosive column at the time of detonation.

(2) There must be adequate space for the broken rock to move and expand. Excessive confinement of explosives is the leading cause of poor blasting results such as backbreak, ground vibrations, airblast, unbroken toe, flyrock, and poor fragmentation.

Properties and Geology of the Rock Mass

The rock mass properties are the single most critical variable affecting the design and results of a blast. The rock properties are very qualitative and cannot be sufficiently quantified numerically when applied to blast design. Rock properties often vary greatly from one end of a construction job to another. Explosive selection, blast design, and delay pattern must consider the specific rock mass being blasted.

Characterizing the Rock Mass

The keys to characterizing the rock mass are a good geologist and a good blasting driller. The geologist must concentrate on detailed mapping of the rock surface for blast design. Jointing probably has the most significant effect on blasting design. The geologist should document the direction, density, and spacing between the joint sets. At least three joint sets—one dominant and two less pronounced—are in most sedimentary rocks. The strike and dip of bedding planes, foliation, and schistosity are also important to blast design and should be documented by the geologist. The presence of major zones of weakness such as faults, open joints, open beds, solution cavities, or zones of less competent rock or unconsolidated material are also important to blast design and must be considered. Samples of freshly broken rock can be used to determine the hardness and density of the rock.

An observant blasting driller can be of great help in assessing rock variations that are not apparent from the surface. Slow penetration, excessive drill noise, and vibration indicate a hard rock that will be difficult to break. Fast penetration and a quiet drill indicate a softer, more easily broken zone of rock. Total lack of resistance to penetration, accompanied by a lack of cuttings or return water or air, means that the drill has hit a void. Lack of cuttings or return water may also indicate the presence of an open bedding plane or other crack. A detailed drill log indicating the depth of these various conditions can be very helpful in designing and loading the blast. The log should be kept by the driller. The driller should also document changes in the color or nature of the drill cuttings which will tell the geologist and blaster the location of various beds in the formation.

Rock Density and Hardness

Some displacement is required to prepare a muckpile for efficient excavation. The density of the rock is a major factor in determining how much explosive is needed to displace a given volume of rock (powder factor). The burden-to-charge diameter ratio varies with rock density, changing the powder factor. The average burden-to-charge diameter ratio of 25 to 30 is for average density rocks similar to the typical rocks listed in table 19-1. Denser rocks such as basalt require smaller ratios (higher powder factors). Lighter materials such as some sandstone or bituminous coal can be blasted with higher ratios (lower powder factors).

The hardness or brittleness of rock can have a significant effect on blasting results. If soft rock is slightly underblasted, the rock probably will still be excavatable. If soft rock is slightly overblasted, excessive violence will not usually occur. On the other hand, slight underblasting of hard rock will often result in a tight muckpile that is difficult to excavate. Overblasting of hard rock is likely to cause excessive flyrock and airblast. Blast designs for hard rock require closer control and tighter tolerances than those for soft rock.

Voids and Zones of Weakness

Undetected voids and zones of weakness such as solution cavities, "mud" seams, and shears are serious problems in

Table 19-1.—Typical rocks, densities, and unit weights

Rock type	Density range (g/cm³)[1]	Range of unit weights	
		U.S. customary (lb/ft³)[2]	Metric (kg/m³)[3]
Limestone	2.5 to 2.8	156 to 174.7	2,500 to 2,800
Schist	2.6 to 2.8	162.2 to 174.7	2,600 to 2,800
Rhyolite	2.2 to 2.7	137.2 to 168.5	2,200 to 2,700
Basalt	2.7 to 2.9	168.5 to 181	2,700 to 2,900
Sandstone	2/0 to 2.6	124.8 to 162.2	2,000 to 2,600
Bituminous coal	1.2 to 1.5	74.9 to 93.6	1,200 to 1,500

[1] Grams per cubic centimeter.
[2] Pounds per cubic foot.
[3] Kilograms per cubic meter.

blasting. Explosive energy always seeks the path of least resistance. Where the rock burden is composed of alternate zones of hard material, weak zones, or voids, the explosive energy will be vented through the weak zones and voids resulting in poor fragmentation. Depending on the orientation of zones of weakness with respect to free faces, excessive violence in the form of airblast and flyrock may occur. When the blasthole intersects a void, particular care must be taken in loading the charge, or the void will be loaded with a heavy concentration of explosive resulting in excessive air-blast and flyrock.

If these voids and zones of weakness can be identified and logged, steps can be taken during borehole loading to improve fragmentation and avoid violence. The best tool for this is a good drill log. The depths of voids and zones of weakness encountered by the drill should be documented. The geologist can help by plotting the trends of "mud" seams and shears. When charging the blasthole, inert stemming materials rather than explosives should be loaded through these weak zones. Voids should be filled with stemming. Where this is impractical because of the size of the void, it may be necessary to block the hole just above the void before continuing the explosive column.

If the condition of the borehole is in doubt, the top of the powder column should be checked frequently as loading proceeds. A void probably exists if the column fails to rise as expected. At this point, a deck of inert stemming material should be loaded before powder loading continues. If the column rises more rapidly than expected, frequent checking will ensure that adequate space is left for stemming.

Alternate zones of hard and soft rock usually result in unacceptably blocky fragmentation. A higher powder factor seldom will correct this problem; it will merely cause the blocks to be displaced farther. Usually, the best way to alleviate this situation is to use smaller blastholes with smaller blast pattern dimensions to get a better powder distribution. The explosive charges should be concentrated in the hard rock.

Jointing

Jointing can have a pronounced effect on both fragmentation and the stability of the perimeter of the excavation. Close jointing usually results in good fragmentation.

Widely spaced jointing, especially where the jointing is pronounced, often results in a very blocky muckpile because the joint planes tend to isolate large blocks in place. Where the fragmentation is unacceptable, the best solution is to use smaller blast holes with smaller blast pattern dimensions. This extra drilling and blasting expense will be more than justified by the savings in loading, hauling, and crushing costs and the savings in secondary blasting.

Where possible, the perimeter holes of a blast should be aligned with the principal joint sets. This produces a more stable excavation, whereas rows of holes perpendicular to a primary joint set produces a more ragged, unstable perimeter (figure 19-1). The jointing will generally determine how the corners at the back of the blast will break out. To minimize backbreak and flyrock, tight corners, as shown in figure 19-2, should be avoided.

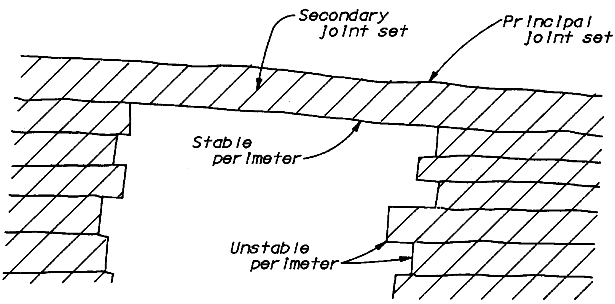

Figure 19-1.—Effect of jointing on the stability of an excavation (plan view).

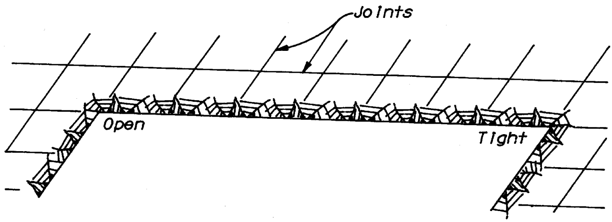

Figure 19-2.—Tight and open corners caused by jointing (plan view).

The open corner at the left of figure 19-2 is preferable. Given the dominant jointing in figure 19-2, more stable conditions will result if the first blast is opened at the far right and designed so that the hole in the rear inside corner contains the highest numbered delay.

Bedding/Foliation

Bedding has a pronounced effect on both the fragmentation and the stability of the excavation perimeter. Open bedding planes, open joints, or beds of weaker materials should be treated as zones of weakness. Stemming, rather than explosive, should be loaded into the borehole at the location of these zones as shown in figure 19-3. In a bed of hard material (greater than 3 feet [1 m] thick), it is often beneficial to load an explosive of higher density than is used in the remainder of the borehole. To break an isolated bed or zone of hard rock (3 feet [1 m] thick or greater) near the collar of the blasthole, a deck charge is recommended, as shown in figure 19-4, with the deck being fired on the same delay as the main charge or one delay later. Occasionally, satellite holes are used to help break a hard zone in the upper part of the burden. Satellite holes (figure 19-4) are short holes, usually smaller in diameter than the main blastholes drilled between the main blastholes.

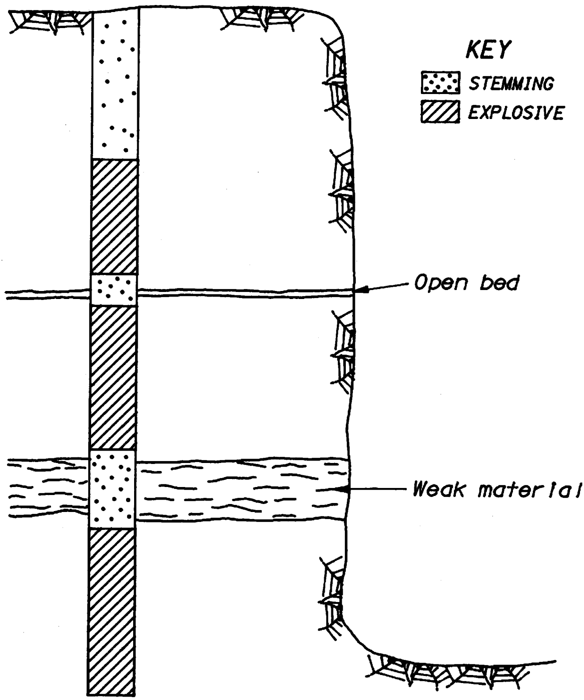

Figure 19-3.—Stemming through weak material and open beds.

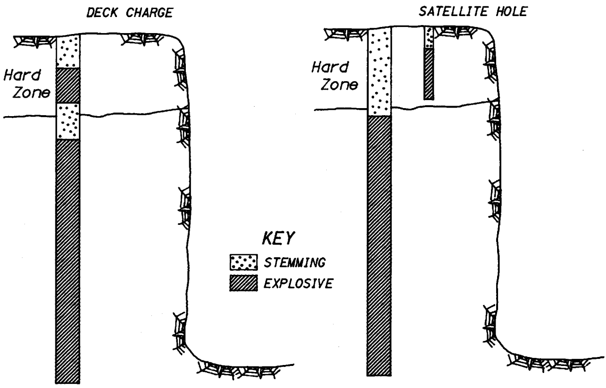

Figure 19-4.—Two methods of breaking a hard collar zone.

A pronounced foliation, bedding plane, or joint is frequently a convenient location for the bench floor. It not only gives a smoother floor but also may reduce subdrilling requirements.

Dipping beds frequently cause stability problems and difficulty in breaking the toe of the excavation. When bedding or foliation dip into the excavation wall, the stability of the slope is enhanced. When the dip is out of the wall, slip planes exist that increase the likelihood of slope deterioration or failure. Blasthole cutoffs (part of a column of explosives not fired) caused by differential bed movement are also more likely. Beds dipping out of the final slope should be avoided wherever possible.

Although beds dipping into the face improve slope stability, the beds can create toe problems because the toe rock tends to break along the bedding or foliation planes.

Dipping beds such as these require a tradeoff, depending upon which is the more serious problem—a somewhat unstable slope or an uneven toe. In some cases, advancing the opening perpendicular to dipping beds may be a compromise.

Many blasting jobs encounter site-specific geologic conditions not covered in this general discussion. Good blasting techniques require constant study of the geology to make every effort to advantageously use the geology, or at least minimize its unfavorable effects in blast designs.

Surface Blasting

Blast Hole Diameter

The blast hole size is the first consideration of any blast design. The blast hole diameter, along with the type of explosive being used and the type of rock being blasted, determines the burden (distance from the blast hole to the nearest free face). All other blast dimensions are a function of the burden. This discussion assumes that the blaster has the freedom to select the borehole size. Many operations limit borehole size based on available drilling equipment.

Practical blasthole diameters for surface construction excavations range from 3 (75 mm) to approximately 15 inches (38 cm). Large blasthole diameters generally yield low drilling and blasting costs because large holes are cheaper to drill per unit volume, and less sensitive, cheaper blasting agents can be used in larger diameter holes. Larger diameter blastholes also allow large burdens and spacings and can give coarser fragmentation. Figure 19-5 illustrates this comparison using 2- (50-mm) and 20-inch (500-mm)-diameter blastholes as an example.

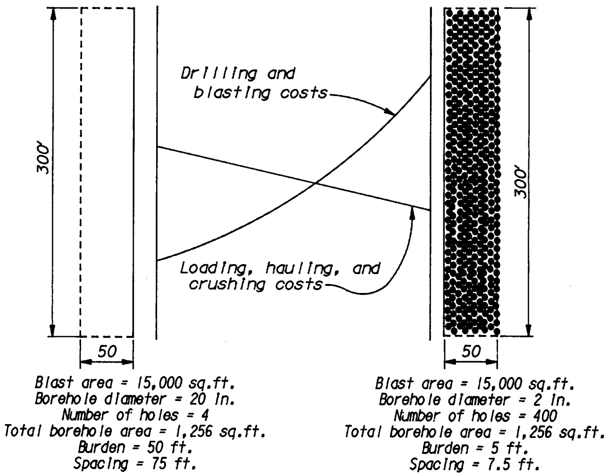

Figure 19-5.—The effect of large and small blast holes on unit costs.

Pattern A contains four 20-inch (500-mm) blast boles, and pattern B contains 400 2-inch (5-mm) blast holes. In all bench blasting operations, some compromise between these two extremes is chosen. Each pattern represents the same area of excavation—15,000 square feet (1,400 m^2)—each involves approximately the same volume of blast holes, and each can be loaded with about the same weight of explosive.

As a general rule, large diameter blast holes (6 to 15 inches [15 to 38 cm]) have limited applications on most construction projects because of the requirements for fine fragmentation and the use of relatively shallow cuts. However, borehole size depends primarily on local conditions. Large holes are most efficient in deep cuts where a free face has already been developed.

In most construction projects, small diameter drilling with high-speed equipment provides relatively low unit costs and permits fairly close spacing of holes. This close spacing provides better distribution of explosives throughout the rock mass, which in turn produces better breakage. An additional advantage of small diameter blast holes is that the reduction in the amount of each explosive used in each hole reduces ground vibrations. Construction blast hole diameters usually vary from 3.5 to 4.5 inches (90 to 114 mm), and the normal drilling depth is less than 40 feet (12 m). Reclamation generally limits blast hole diameters for structural excavation drilling to 3.5 inches (90 mm). Blasting patterns usually range from 6 by 8 feet (1.8 by 2.4 meters) to 8 by 15 feet (2.4 by 4.6 m) and are usually rectangular with the burden being less than the spacing.

In a given rock type, a four-hole pattern will give relatively low drilling and blasting costs. Drilling costs for large blastholes will be low, a low-cost blasting agent will be used, and the cost of detonators will be minimal. In a difficult blasting situation, the broken material will be blocky and nonuniform in size, resulting in higher loading, hauling, and crushing costs as well as requiring more secondary breakage. Insufficient breakage at the toe may also result.

The 400-hole pattern will yield high drilling and blasting costs. Small holes cost more to drill per unit volume, powder for small diameter blastholes is usually more expensive, and the cost of detonators will be higher. The fragmentation will be finer and more uniform, resulting in lower loading, hauling, and crushing costs. Secondary blasting and toe problems will be minimized. Size of equipment, subsequent processing required for the blasted material, and economics will dictate the type of fragmentation needed and the size of blast hole to be used.

Geologic structure is a major factor in determining the blast hole diameter. Planes of weakness (i.e., joints, shears, or zones of soft rock) tend to isolate large blocks of rock in the burden. The larger the blast pattern, the more likely these blocks are to be thrown unbroken into the muckpile. Note that in the top pattern in figure 19-6, some of the blocks are not penetrated by a blast hole. In the smaller bottom pattern, all the blocks contain at least one blast hole. Because of the better explosives distribution, the bottom pattern will give better fragmentation.

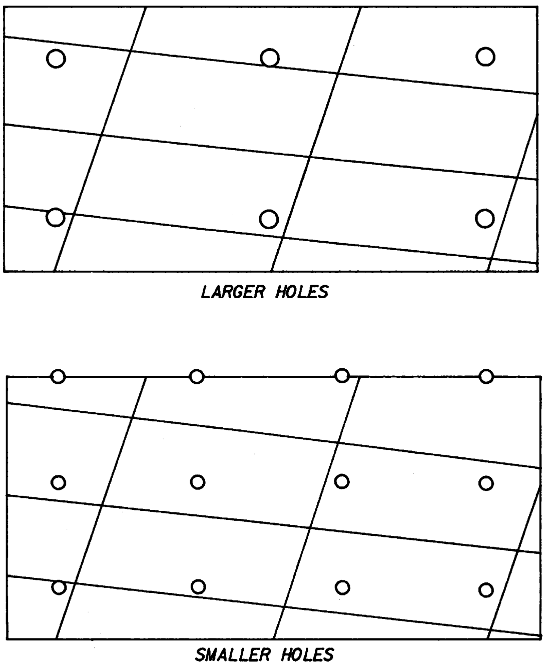

Figure 19-6.—The effects of jointing on selection of blast hole size.

Airblast and flyrock often occur because of an insufficient collar distance (stemming column) above the explosive charge. As the blast hole diameter increases, the collar distance required to prevent violence increases. The ratio of collar distance to blast hole diameter required to prevent violence varies from 14:1 to 28:1, depending on the relative densities and velocities of the explosive and rock, the physical condition of the rock, the type of stemming used, and the point of initiation. A larger collar distance is required where the sonic velocity of the rock exceeds the detonation velocity of the explosive or where the rock is heavily fractured or low density. A top-initiated charge requires a larger collar distance than a bottom-initiated charge. As the collar distance increases, the powder distribution becomes poorer, resulting in poorer fragmentation of the rock in the upper part of the bench.

Ground vibrations are controlled by reducing the weight of explosive fired per delay interval. This is done more easily with small blast holes than with large blast holes. In many situations where large diameter blast holes are used near populated areas, several delays, along with decking, must be used within each hole to control vibrations.

Large holes with large blast patterns are best suited to an operation with: (1) a large volume of material to be moved, (2) large loading, hauling, and crushing equipment, (3) no requirement for fine, uniform fragmentation, (4) an easily broken toe, (5) few ground vibration or airblast problems (few nearby buildings), and (6) a relatively homogeneous, easily fragmented rock without many planes of weakness or voids. Many blasting jobs have constraints that require smaller blast holes.

The final selection of blast hole size is based on economics. Savings realized through inappropriate cost cutting in the drilling and blasting program may well be lost through increased loading, hauling, or crushing costs.

Blast Patterns

The three drill patterns commonly used are square, rectangular, and staggered. The square drill pattern (figure 19-7) has equal burdens and spacing, and the rectangular pattern has a larger spacing than burden. In both the square and rectangular patterns, the holes of each row are lined up directly behind the holes in the preceding row. In the staggered pattern (figure 19-8), the holes in each are positioned in the middle of the spacings of the holes in the preceding row. In the staggered pattern, the spacings should be larger than the burden.

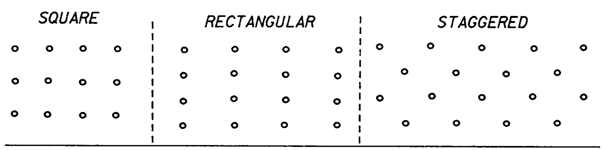

Figure 19-7.—Three basic types of drill patterns.

Square or rectangular drilling patterns are used for firing V-cut (figure 19-9) or echelon rounds. The burdens and subsequent rock displacement are at an angle to the original free face either side of the blast round in V-cut or echelon patterns. The staggered drilling pattern is used for row-on-row firing where the holes of one row are fired before the holes in the row immediately behind them as shown in figure 19-9. Looking at figure 19-9, with the burdens developed at a 45-degree angle to the original

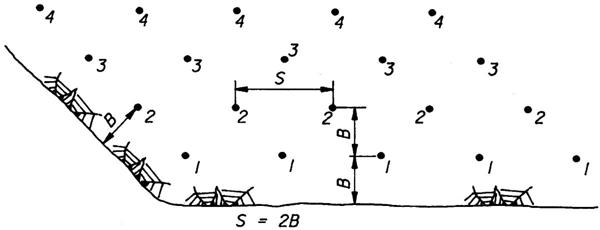

Figure 19-8.—Corner cut staggered pattern with simultaneous initiation within rows (blast hole spacing, S, is twice the burden, B).

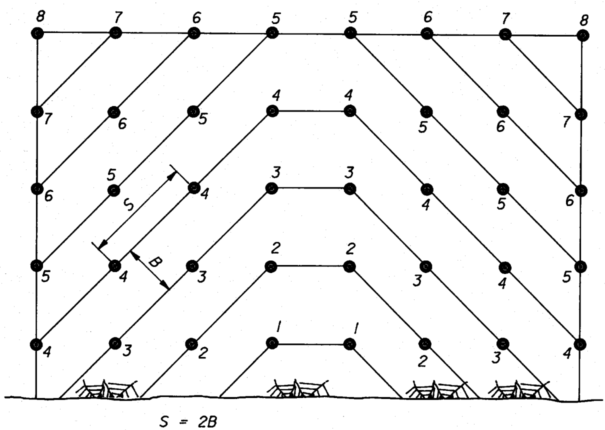

Figure 19-9.—V-Echelon blast round (true spacing, S, is twice the true burden, B).

free face, the original square drilling pattern has been transformed to a staggered blasting pattern with a spacing twice the burden. The three simple patterns discussed here account for nearly all the surface blasting.

Burden

Figure 19-10 is an isometric view showing the relationship of the various dimensions of a bench blast. The burden is defined as the distance from a blast hole to the nearest free face at the instant of detonation. In multiple row blasts, the burden for a blast hole is not necessarily measured in the direction of the original free face. The free faces developed by blast holes fired on lower delay periods must be taken into account. As an

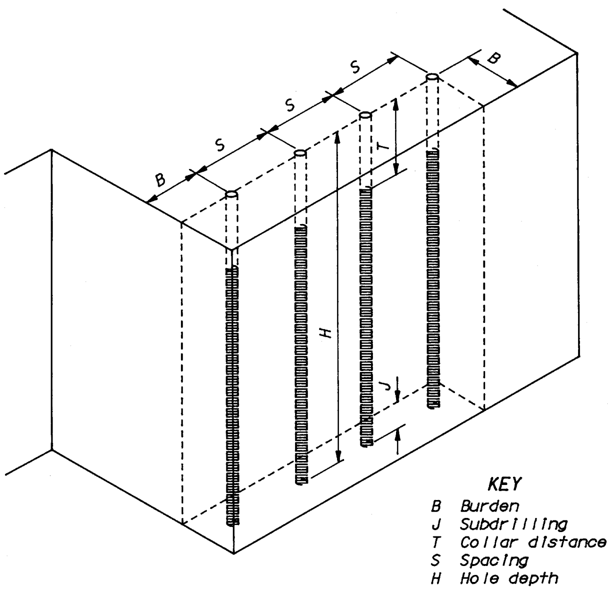

Figure 19-10.—Isometric view of a bench blast.

example, in figure 19-8, where one entire row is blasted before the next row begins, the burden is measured perpendicular between rows.

In figure 19-9, the blast progresses in a V-shape. The true burden on most of the holes is measured at an angle of 45 degrees from the original free face.

It is very important that the proper burden be calculated, accounting for the blast hole diameter, relative density of the rock and explosive, and, to some degree, the depth of the blast hole. An insufficient burden will cause excessive airblast and flyrock. Too large a burden will produce inadequate fragmentation, toe problems, and excessive ground vibrations. If it is necessary to drill a round before the previous round has been excavated, it is important to stake out the first row of the second round before the first round is fired. This will ensure a proper burden on the first row of blast holes in the second blast round.

For bulk-loaded charges (the charge is poured down the hole), the charge diameter is equal to the blast hole diameter. For tamped cartridges, the charge diameter will be between the cartridge diameter and the blast hole diameter, depending on the degree of tamping. For untamped cartridges, the charge diameter is equal to the cartridge diameter. When blasting with ANFO (ammonium nitrate/fuel oil mixture) or other low density blasting agents with densities near 53 lb/ft^3 (0.85 g/cm^3), in typical rock with a density near 170 lb/ft^3 (2.7 g/cm^3, the normal burden is approximately 25 times the charge diameter. When using denser products such as slurries or dynamites with densities near 75 lb/ft^3 (1.2 g/cm^3), the normal burden is approximately 30 times the charge diameter. These are first approximations, and field testing usually results in adjustments to these values.

The burden-to-charge-diameter ratio is seldom less than 20 or seldom more than 40, even in extreme cases. For instance, when blasting with a low density blasting agent such as ANFO in a dense formation such as basalt, the desired burden may be about 20 times the charge diameter. When blasting with denser slurries or dynamites in low density formations such as sandstones, the burden may approach 40 times the charge diameter. Table 19-2 summarizes these approximations.

Table 19-2.—Approximate burden charge diameter ratios for bench blasting

Material	Ratio
ANFO (density 53.1 lb/ft^3, 0.85 g/cm^3)	
Light rock (density ~ 137.3 lb/ft^3, 2.2 g/cm^3)	28
Average rock (density ~ 168.6 lb/ft^3, 2.7 g/cm^3)	25
Dense rock (density ~ 199.8 lb/ft^3, 3.2 g/cm^3)	23
Slurry, dynamite (density ~ 199.7 lb/ft^3, 3.2 g/cm^3)	
Light rock (density ~ 137.3 lb/ft^3, 2.2 g/cm^3,)	33
Average rock (density ~ 168.6 lb/ft^3, 2.7 g/cm^3)	30
Dense rock (density ~ 199.8 lb/ft^3, 3.2 g/cm^3)	27

High-speed photographs of blasts show that flexing of the burden plays an important role in rock fragmentation. A relatively deep, narrow burden flexes and breaks more easily than a shallow, wider burden. Figure 19-11 shows the difference between using a 6-inch (150-mm) blast hole and a 12.25-inch (310-mm) blast hole in a 40-foot (12-m) bench with a burden-to-charge-diameter ratio of 30 and appropriate subdrilling and stemming dimensions. Note the inherent stiffness of the burden with a 12.25-inch (310-mm) blast hole as compared to a 6-inch (150-mm)

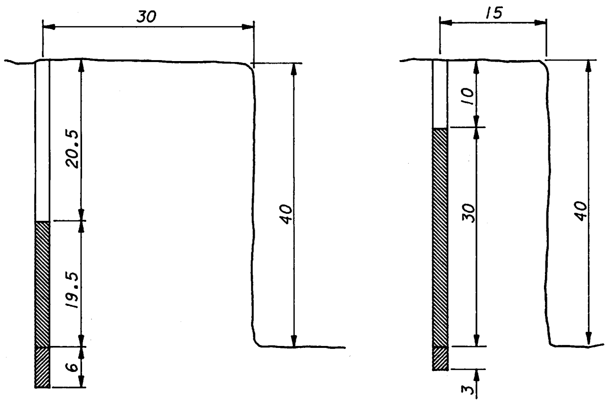

Figure 19-11.—Comparison of a 12¼-inch- (300-mm) diameter blast hole (stiff burden) on the left with a 6-inch- (150-mm) diameter blast hole (flexible burden) on the right in a 40-foot (12-m) bench.

blast hole. Based on this, lower burden-to-charge-diameter ratios should be used as a first approximation when the blast hole diameter is large in comparison to the bench height. Care must be taken that the burden ratio is not so small as to create violence. Once the ratio has been determined, it becomes the basis for calculating subdrilling, collar distance (stemming), and spacing.

Subdrilling

Subdrilling is the distance drilled below the floor level to ensure that the full face of rock is removed. Where there is a pronounced parting at floor level for the explosive charge to conveniently break, subdrilling may not be required. In coal strip mining, it is common practice to drill down to the coal and then backfill a foot or two before loading explosives, resulting in a negative subdrill. In most surface blasting jobs, some subdrilling is necessary to make sure the shot pulls to grade. In most construction blasting, subdrilling is generally limited to 10 percent or less of the bench height. In blasting for civil engineering structures where a final grade is specified, subdrilling of the final lift is severely restricted. The final lift in structural excavations is usually limited to 5 or 10 feet (1.5 to 3 m). Subdrilling is not allowed in a 5-foot (1.5-m) lift and is limited to 2 feet (0.6 m) for the 10-foot (3-m) lift. To prevent damage to the foundation, the diameter of the blast hole is limited to 3.5 inches (90 mm).

Priming the explosive column at the toe level (bottom of the drill hole) gives maximum confinement and normally gives the best breakage. Toe priming usually requires less subdrilling than collar priming. Toe priming should be restricted in structural foundations because of the potential damage to the unshot rock.

Excessive subdrilling is unnecessary, expensive, and may cause excessive ground vibrations because of the high degree of confinement of the explosive in the bottom of the blast hole, particularly when the primer is placed in the bottom of the hole. In multiple-bench operations, excessive subdrilling may cause undue fracturing in the upper portion of the bench below, creating difficulties in collaring holes in the lower bench. Insufficient subdrilling causes a high bottom, resulting in increased wear and tear on equipment and expensive secondary blasting or hand excavation in structural foundations.

Collar Distance (Stemming)

Collar distance is the distance from the top of the explosive charge to the collar of the blast hole. This zone usually is filled with an inert material called stemming to give some confinement to the explosive gases and to reduce airblast. A well-graded, crushed gravel works best as stemming, but it is common practice to use drill cuttings because of availability and economics. Collar distances that are too short result in excessive violence in the form of airblast and flyrock and may cause backbreak (breaking beyond the back wall). Collar distances that are too long create large blocks in the upper part of the muck pile. The selection of a collar distance is often a tradeoff between fragmentation and the amount of airblast and flyrock that can be tolerated. This is true especially where the upper part of the bench contains rock that is difficult to break or is of a different type. The difference between a violent blast and one that fails to fragment the upper zone properly may be a matter of only a few feet of stemming. Collar or direct priming (placing the primer at or near the collar of the blast hole with the blasting cap pointing toward the bottom of the hole) of blast holes normally causes more violence than center or toe priming and requires the use of a longer collar distance.

Field experience has shown that a collar distance equal to 70 percent of the burden is a good first approximation. Careful observation of airblast, flyrock, and fragmentation will enable further refinement of this dimension. Where adequate fragmentation in the collar zone cannot be attained while still controlling airblast and flyrock, deck charges or satellite (mid-spaced) holes may be required (figure19-4).

A deck charge is an explosive charge near the top of the blast hole, separated from the main charge by inert stemming. If large blocky materials are being created in the collar zone and less stemming would cause excessive airblast or flyrock, the main charge should be reduced slightly and a deck charge added. The deck charge is usually shot on the same delay as the main charge or one delay later. Do not place the deck charge too near the top of the blast hole, or excessive flyrock may result. Alternatively, short satellite holes between the main blast holes can be used. The diameter of the satellite holes is usually smaller than the main blast holes, and the satellite holes are loaded with a light charge of explosives.

Collar distance is a very important blast design variable. One violent blast can permanently alienate neighbors. In a delicate situation, it may be best to start with a collar distance equal to the burden and gradually reduce this if, conditions warrant. Collar distances greater than the burden are seldom necessary.

Spacing

Spacing is defined as the distance between adjacent blast holes, measured perpendicular to the burden. Where the rows are blasted one after the other as in figure 19-8, the spacing is measured between holes in a row. Where the blast progresses at an angle to the original free face, as in figure 19-9, the spacing is measured at an angle from the original free face.

Spacing is calculated as a function of the burden and also depends on the timing between holes. Spacing that is too close causes crushing and cratering between holes, large blocks in the burden, and toe problems. Spacing that is too wide causes inadequate fracturing between holes, toe problems, and is accompanied by humps on the face (figure 19-12).

When the holes in a row are initiated on the same delay period, a spacing equal to twice the burden usually will pull the round satisfactorily. The V-cut round in

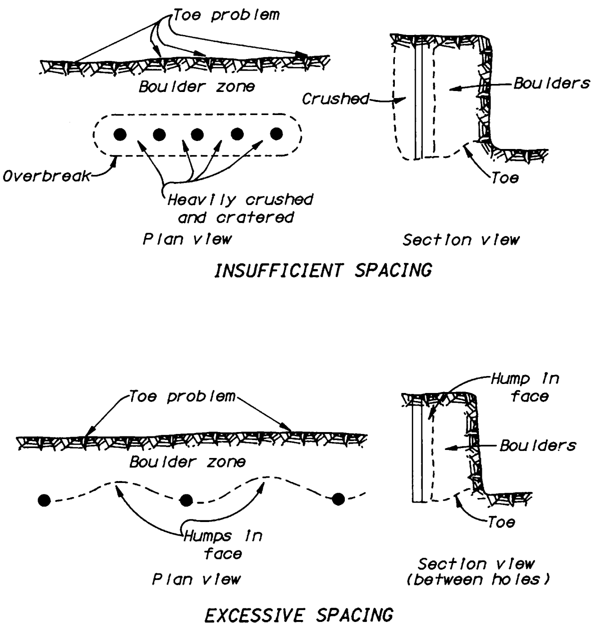

Figure 19-12.—Effects of too small and too large spacing.

figure 19-9 illustrates simultaneous initiation within a row, with the rows being the angled lines of holes fired on the same delay. The true spacing is twice the true burden, even though the holes originally were drilled on a square pattern.

Field experience has shown that the use of millisecond (ms) delays between holes in a row results in better fragmentation and also reduces ground vibrations produced by the blast. When ms delays are used between holes in a row, the spacing-to-burden ratio must be reduced to somewhere between 1.2 and 1.8, with 1.5 being a good first approximation. Various delay patterns may be used within the rows, including alternate delays (figure 19-13) and progressive delays (figure 19-14). Generally, large diameter blast holes require lower spacing-to-burden ratios (usually 1.2 to 1.5 with ms delays) than small diameter blast holes (usually 1.5 to 1.8). Because of the geology complexities, the interaction of delays, differences in explosive and rock strengths, and other variables, the proper spacing-to-burden ratio must be determined through onsite experimentation, using the preceding values as first approximations.

Except when using controlled blasting techniques such as smooth blasting and cushion blasting, described later, the spacing should never be less than the burden.

Hole Depth

In any blast design, the burden and the blast hole depth (or bench height) must be reasonably compatible. The rule of thumb for bench blasting is that the hole depth-to-burden ratio should be between 1.5 and 4.0. Hole depths

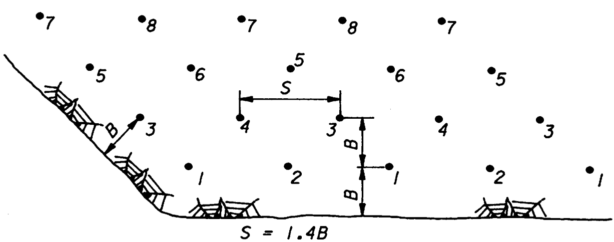

Figure 19-13.—Staggered blast pattern with alternate delays (blast hole spacing, S, is 1.4 times the burden, B).

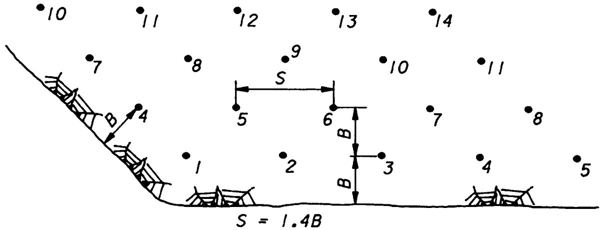

Figure 19-14.—Staggered blast pattern with progressive delays (blast hole spacing, S, is 1.4 times the burden, B).

less than 1.5 times the burden cause excessive air blast and fly rock and, because of the short, thick shape of the burden, give coarse and uneven fragmentation. Where operational conditions require a ratio of less than 1.5, a primer should be placed at the toe of the bench to assure maximum confinement. Keep in mind that placing the primer in the subdrill can cause increased ground vibrations and unacceptably irregular final grades for engineering structures. If the use of a hole depth-to-burden ratio of less than 1.5 is necessary or specified, consideration should be given to increasing the bench height or using smaller drill hole diameters.

Hole depths greater than four times the burden are also undesirable. The longer a hole is with respect to its diameter, the more error there will be in the hole location at toe level (hole wandering), the most critical portion of the blast. A poorly controlled blast will result. Extremely long, slender holes have been known to intersect.

High benches with short burdens can also create safety hazards, such as small equipment having to drill the front row of holes near the edge of a high ledge or a small shovel having to dig at the toe of a precariously high face. The obvious solution to this problem is to use a lower bench height. There is no real advantage to a high bench. Lower benches yield more efficient blasting results, lower drilling costs, less chance of cutoffs, and are safer. If it is impractical to reduce the bench height, larger rock handling and drilling equipment should be used, effectively reducing the blast hole depth-to-burden ratio.

A major problem with long slender charges is the greater potential for cutoffs in the explosive column. If it is necessary to use blast designs with large hole depth-to-burden ratios, multiple priming should be used as insurance against cutoffs.

Delays

Millisecond delays are used between charges in a blast round to:

- To ensure that a proper free face is developed to enable the explosive charge to efficiently fragment and displace the rock

- To enhance fragmentation between adjacent holes

- To reduce the ground vibrations created by the blast

Numerous delay patterns exist, several of which are covered in figures 19-8, 19-9, 19-13, and 19-14. Keep in mind the following:

- The delay time between holes in a row should be between 1 and 5 ms per foot (0.3 m) of burden. Delay times less than 1 ms per foot of burden cause premature shearing between holes, resulting in coarse fragmentation. If an excessive delay time is used between holes, rock movement from the first hole prevents the adjacent hole from creating additional fractures between the two holes. A delay of 3 ms per foot (0.3 m) of burden gives good results in many types of rock.

- The delay time between rows should be two to three times the delay time between holes in a row. To obtain good fragmentation and to control fly rock, a sufficient delay is needed so that the burden from previously fired holes has enough time to move forward to accommodate moving rock from subsequent rows. If the delay between rows is too short, movement in the back rows will be upward rather than outward (figure19-15).

- Where airblast is a problem, the delay between holes in a row should be at least 2 ms per foot of spacing. This prevents airblast from one charge from adding to that of subsequent charges as the blast proceeds down the row.

- For controlling ground vibrations, most regulatory authorities consider two charges to be separate events if they are separated by a delay of 9 ms or more.

These rules-of-thumb generally yield good blasting results. When using surface delay systems such as detonating cord connectors and sequential timers, the chances for cutoffs will be increased. To solve this problem, in-hole delays should be used in addition to the surface delays. When using surface detonating cord connectors, the use of 100-ms delays in each hole is suggested. This will cause ignition of the in-hole delays well in advance of

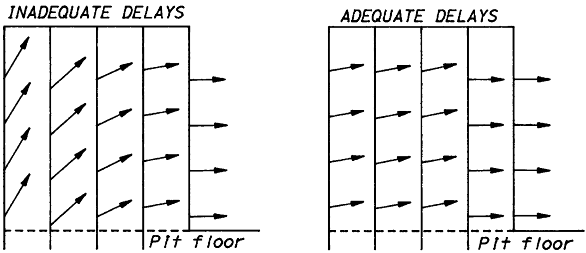

Figure 19-15.—The effect of inadequate delays between rows.

rock movement, thus minimizing cutoffs. The same effect can be accomplished with a sequential timer by avoiding the use of electric caps with delays shorter than 75 to 100 ms.

It is best if all the explosive in a blast hole is fired as a single column charge. When firing large blast holes in populated areas, two or more delays within a blast hole can be used to reduce ground vibrations. Blast rounds of this type can become quite complex.

All currently used delay detonators employ pyrotechnic delay elements that depend on a burning powder train for their delay. Although these delays are reasonably accurate, overlaps have been known to occur. When it is essential that one charge fires before an adjacent charge, such as in a tight corner of a blast, it is a good idea to skip a delay period.

Powder Factor

Powder factor, or pounds of explosive per cubic yard (kg/m^3) of rock, is not the best tool for designing blasts.

Blast designs should be based on the dimensions discussed earlier in this chapter. Powder factor is a necessary calculation for cost accounting purposes. In construction blasting where the excavated material has little or no inherent value, powder factor is usually expressed in pounds of explosives per cubic yard of material broken. Powder factors for surface blasting can vary from 0.25 to 2.5 pounds per cubic yards (lb/yd^3 [0.1 to 1.1 kg/m^3]), with 0.5 to 1.0 lb/yd^3 (0.2 to 0.45 kg/m^3) being most typical.

Powder factor for a single blast hole is calculated by the following:

$$\boldsymbol{P.F.} = \frac{\boldsymbol{L}(0.340\boldsymbol{d})(\boldsymbol{D}^2)}{27\boldsymbol{BSH}}$$

P.F.	=	Powder factor in pounds of explosive per cubic yard of rock
L	=	Length of explosive charge in feet
d	=	Density of explosive charge in grams per cubic centimeter
D	=	Charge diameter in inches
B	=	Burden in feet
S	=	Spacing in feet
H	=	Bench height

A comparable formula can be developed for metric equivalents. Many companies that provide explosives also publish tables that give loading densities in pounds per foot of blast hole for different combinations of d and D. A common nomograph found in most blasting handbooks can be used to calculate the density in pounds per foot of borehole. The powder factor is a function of the explosive type, rock density, and geologic structure. Table 19-3 includes typical powder factors for surface blasting.

Table 19-3.—Typical powder factors for surface blasting

Rock breakage difficulty	Powder factor	
	(lb/yd^3)	(kg/m^3)
Low	0.25-0.40	0.1-0.18
Medium	0.40- 0.75	0.18-0.34
High	0.75-1.25	0.34-0.57
Very high	1.25-2.50	0.57-1.14

Higher energy explosives, such as those containing large amounts of aluminum, can break more rock per unit weight than lower energy explosives. Most of the commonly (lower energy) used explosive products have similar energy values and, thus, have similar rock breaking capabilities. Soft, low density rock requires less explosive than hard, dense rock. Large hole patterns require less explosive per volume of rock because a larger portion of stemming is used. Poor powder distribution in larger diameter blast holes frequently results in coarser fragmentation. Massive rock with few existing planes of weakness requires a higher powder factor than a rock unit with numerous, closely spaced joints or fractures. The more free faces a blast has to break to, the lower the powder factor requirement. A corner cut (figure19-8), with two vertical free faces, requires less powder than a box cut (figure19-9) or angled cuts (figure19-16) with only one vertical free face, which, in turn, will require less powder than a shaft sinking type or parallel cut (figure19-16) where there are no free faces. In a shaft sinking cut, it is desirable to open a second free face by

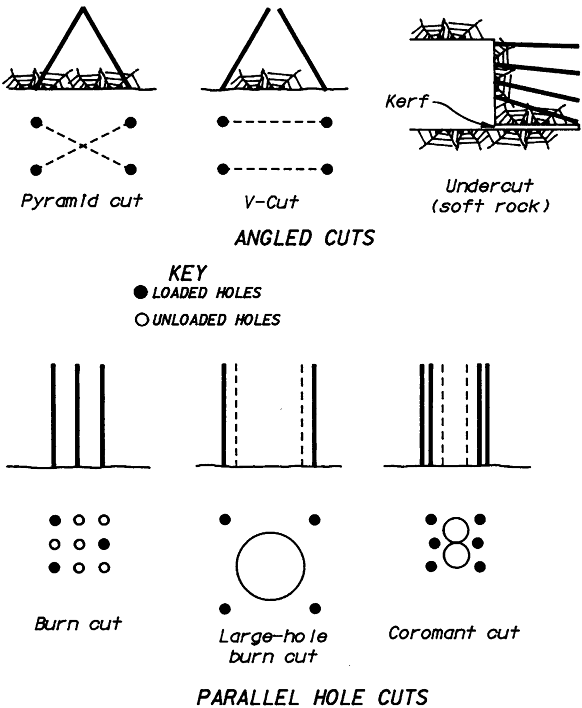

Figure 19-16.—Types of opening cuts.

creating a V-cut somewhere near the center of the round. V-cuts are discussed in the "Underground Blasting" section of this chapter.

When blasted materials have an inherent value per ton, such as aggregate or ore, powder factors are expressed as unit weight of explosives per ton of rock or tons of rock per unit weight of explosive.

Secondary Blasting

Some primary blasts will result in fragments too large to be handled efficiently by the loading equipment and will cause plugging of crushers or preparation plants. Secondary fragmentation techniques must be used to break these oversize fragments. If fragments are too large to be handled, the loader operator will set the rock aside for treatment. Identifying material large enough to cause crusher plugging is not always easy. The loader operator must be knowledgeable enough to watch for material that is small enough for convenient loading but that is too large for the crusher.

Secondary fragmentation can be accomplished by:

- A heavy ball (headache ball) suspended from a crane may be dropped repeatedly on the oversize fragment until it breaks. This is a relatively inefficient method, and breaking a large or tough (nonbrittle) rock may take considerable time. This method is adequate where the number of oversize fragments is small.

- A hole may be drilled into the oversize fragment and a hydraulic wedging device inserted to split the rock. This is also a slow method but may be satisfactory where a limited amount of secondary fragmentation is necessary. An advantage to this method is that it does not create the flyrock associated with explosives and, to some degree, with the headache ball method.

- An explosive may be packed loosely into a crack or depression in the oversize fragment then covered with a damp earth material and fired. This type of charge is called a mudcap, plaster, or adobe charge. This method is inefficient because of the limited explosive confinement and the relatively large amount of explosives required. Other results are excessive noise, flyrock, and often, inadequate fragmentation. This method is also hazardous because the primed charge lying on the surface is prone to accidental initiation by external impacts from falling rocks or equipment. External charges should be used to break boulders only where drilling is impractical.

- The most efficient method of secondary fragmentation is through the use of small (1- to 3-inch [25- to 75-mm]) blast holes. The blast hole is normally collared at the most convenient location, such as a crack or depression in the rock, and is directed toward the center of the mass. The hole is drilled two-thirds to three-fourths of the way through the rock. Because the powder charge is surrounded by free faces, less explosive is required to break a given amount of rock than in primary blasting. One-quarter pound per cubic yard (0.1 kg/m^3) usually is adequate. Careful location of the charge is more important than its precise size. When in doubt, it is best to estimate on the low side and under load the hole. For larger fragments, it is best to drill several holes and distribute the explosive charge rather than place the entire charge in a single hole. All secondary blast holes should be stemmed. Usually, secondary blasts are more violent than primary blasts. Any type of initiation system may be used to initiate a secondary blast and for connecting large numbers of oversize fragments. Detonating cord often is used where noise is not a problem.

Although secondary blasting employs relatively small charges, the potential safety hazards must not be underestimated. Usually, there is more flyrock, and the flyrock is less predictable than with primary blasting.

Underground Blasting

Underground blast rounds are divided into two basic categories:

(1) Heading, drift, or tunnel rounds, where the only free face is the surface from which the holes are drilled

(2) Bench or stope rounds, where there is one or more free faces in addition to the face where the blast holes are drilled.

In the second category, blast rounds are designed in the same manner as surface blast rounds. Only the blast rounds that are in the first category (those with only one initial free face) are discussed below.

Opening Cuts

The initial and most critical part of a heading round is the opening cut. The essential function of this cut is to provide additional free faces where the rock can be broken. Although there are many specific types of opening cuts and the terminology can be quite confusing, all opening cuts fall into one of two classifications—angled cuts or parallel hole cuts (figure 19-16).

An angled cut, also referred to as a V-cut, draw cut, slab cut, or pyramid cut, breaks out a wedge of rock to create an opening that the remaining burden can move into. Angled cuts are very difficult to drill accurately. The bottoms of each pair of cut holes should be as close together as possible but must not cross. If they cross, the depth of round pulled will be less than designed. If the hole bottoms are more than a foot or so apart, the round may not pull to the proper depth. The angle between the cut holes should be 60 degrees or more to minimize bootlegging. One method to ensure getting a standard angle cut is to supply the drillers with a template with the proper spacing and angles for the angled holes. The selection of the specific type of angled cut is a function of the rock, the type of drilling equipment, and the philosophy of the blasting supervisor. A considerable amount of trial and error usually is involved in determining the best angle cut for a specific site. In small diameter tunnels with narrow headings, it is often impossible to position the drill properly to drill an angled cut. In this case, a parallel hole cut must be used.

Parallel hole cuts, also referred to as Michigan cuts, Cornish cuts, shatter cuts, burn cuts, or Coromant cuts, are basically a series of closely spaced holes, some loaded and some unloaded (figure 19-17) that, when fired, pulverize and eject a cylinder of rock to create an opening where the remaining burden can be broken. Because they require higher powder factors and more drilling per volume of rock blasted, the use of parallel hole cuts usually is restricted to narrow headings where there is not enough room to drill an angled cut.

Parallel hole cuts involve more drilling than angled cuts because the closely spaced holes break relatively small volumes of rock. Parallel cuts are relatively easy to drill because the holes are parallel. Like angled cuts, accurately drilled parallel hole cuts are essential if the blast round is to be effective. Some drill jumbos have automatic controls to ensure that holes are drilled parallel. Drill jumbos of this type are a good investment where parallel hole cuts will be drilled routinely. A template also may

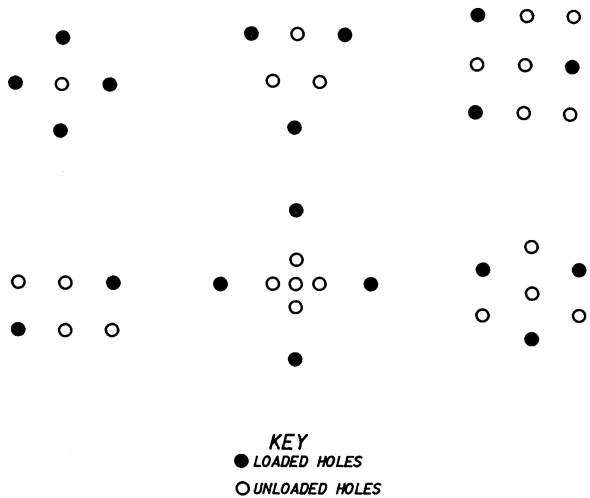

Figure 19-17.—Six designs for parallel hole cuts.

be used in drilling a parallel hole cut. The selection of the type of parallel hole cut also depends on the rock, the type of drilling equipment, and the philosophy of the blasting supervisor. As with angled cuts, trial and error usually is involved in determining the best parallel hole cut for a specific site.

All types of opening cuts must pull to the planned depth because the remainder of the round will not pull more deeply than the opening cut. In blasting with burn cuts, care must be exercised to prevent overloading of the burn holes because overloading may cause the cut to “freeze” or not pull properly. The design of the cut depends on the type of rock and often must be designed and refined by trial and error.

The advantage of a large central hole is that the hole gives a dependable free face where succeeding holes can break. This free face is not always obtained with standard burn cuts. The large central hole ensures a more dependable and deeper pull of the blast round. The disadvantages of a large central hole are the requirements for the proper equipment to drill the large central hole as well as extra time. Intermediate-sized holes, usually 4 to 5 inches (100-130 mm) in diameter, are sometimes drilled using the standard blast hole equipment as a compromise.

In some soft materials, particularly coal, the blasted cut is replaced by a sawed kerf, usually at floor level (figure 19-18). In addition to giving the material a dependable void to break into, the sawed cut ensures that the floor of the opening will be smooth.

Blasting Rounds

Once the opening cut has established the necessary free face, the remainder of the blast holes must be designed so that the burden successively breaks into the void space. The progression of the blast round should provide a proper free face parallel or nearly parallel to the hole at its time of initiation. Figure 19-19 gives the typical nomenclature for blast holes in a heading round.

The holes fired immediately after the cut holes are called the relievers. The burden between these holes must be planned carefully. If the burden is too small, the charges will not pull their share of the round. If the burden is too large, the round may freeze because the rock will have insufficient space to expand. After several relievers have been fired, the opening usually is large enough to permit the remainder of the blast to be designed, as discussed under “Surface Blasting.” Where heading rounds are large, the burden and spacing ratio usually is slightly less

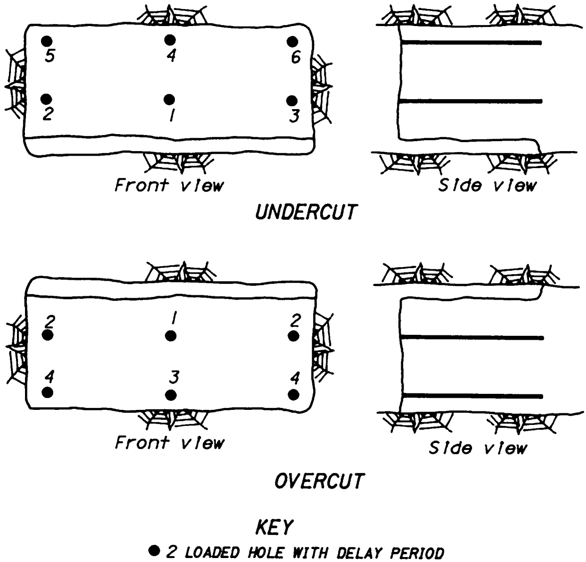

Figure 19-18.—Blast round for soft rock using sawed kerf (numbers on loaded holes show delay in milliseconds.)

than that for surface blasts. In small headings where space is limited, the burden and spacing ratio will be still smaller. Trial and error plays an important part in this type of blast design.

The last holes to be fired in an underground round are the back holes at the top, the rib holes at the sides, and the lifters at the bottom of the heading. Unless controlled blasting is used (discussed below), the spacing between these perimeter holes is about 20 to 25 blast hole diameters. Figure 19-20 shows two typical angled cut blast rounds. After the initial wedge of rock is extracted by the cut, the angles of the subsequent blast holes are

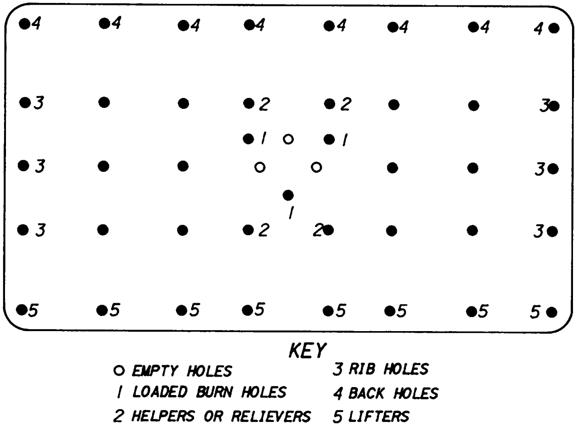

Figure 19-19.—Nomenclature for blast holes in a heading round.

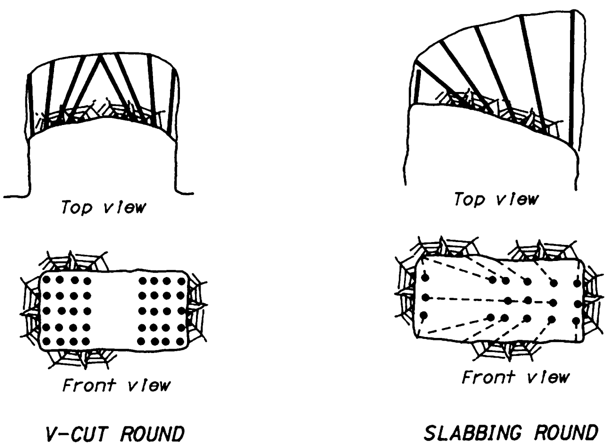

Figure 19-20.—Angled cut blast rounds.

reduced progressively until the perimeter holes are parallel to the heading or looking slightly outward. In designing burden and spacing dimensions for angled cut blast rounds, the location of the bottom of the hole is considered rather than the collar.

Figure 19-21 shows two typical parallel hole cut blast rounds. These rounds are simpler to drill than angled cut rounds. Once the central opening has been established, the round resembles a bench round turned on its side. Figure 19-22 shows a comparison of typical muckpiles obtained from V-cut and burn-cut blast rounds. Burn cuts give more uniform fragmentation and a more compact muckpile than V-cuts. V-cut muckpiles are more spread out and vary in fragmentation. Powder factors and the amount of drilling required are higher for burn cuts.

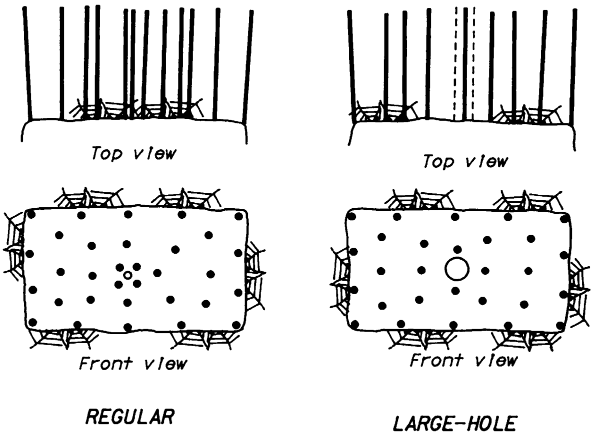

Figure 19-21.—Parallel hole cut blast rounds.

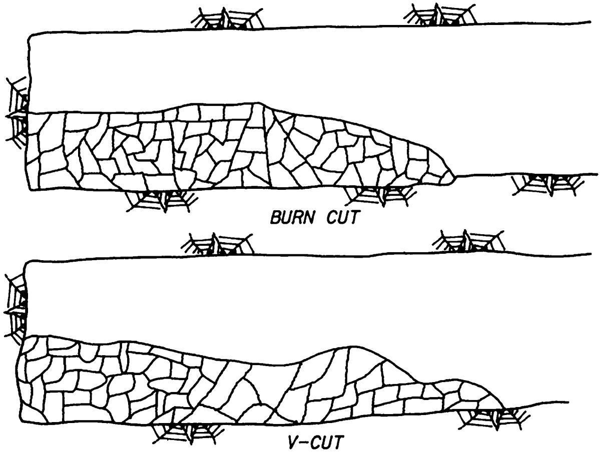

Figure 19-22.—Fragmentation and shape of muckpile as a function of type of cut.

Delays

Two series of delays are available for underground blasting—millisecond delays, the same as those used in surface blasting; and slow, or tunnel delays. The choice of delay depends on the size of the heading being blasted and on the fragmentation and type of muckpile desired. Slow delays give coarser fragmentation and a more compact muckpile. Millisecond delays give finer fragmentation and a looser muckpile (figure19-23). In small headings where space is limited, particularly when using parallel hole cut rounds, slow delays are necessary to ensure that the rock from each blast hole has time to be ejected before the next hole fires. Where delays intermediate between millisecond delays and slow delays is desired, use millisecond delays and skip delay periods.

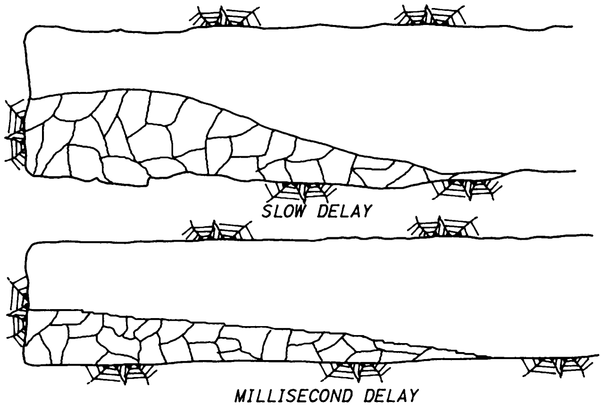

Figure 19-23.—Fragmentation and shape of muckpile as a function of delay.

In an underground blast round, the delay pattern must be designed so that at the time of firing each hole has a good free face where the burden can be displaced. Figure 19-24 shows a typical delay pattern for a burn cut blast round in a heading in hard rock. Figure 19-25 shows a delay pattern for a V-cut blast round.

The shape of the muckpile is affected by the order that the delays are fired (figure19-26). If the blast is designed so that the back holes at the roof are fired last, a cascading effect is obtained, resulting in a compact muckpile. If the lifters are fired last, the muckpile will be displaced away from the face.

Powder Factor

As with surface blasting, powder factors for underground blasting vary depending on several things. Powder factors for underground blasting may vary from 1.5 to

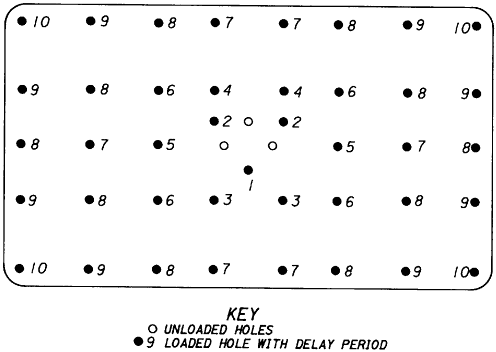

Figure 19-24.—Typical burn cut blast round delay pattern (numbers on loaded holes show delay in milliseconds).

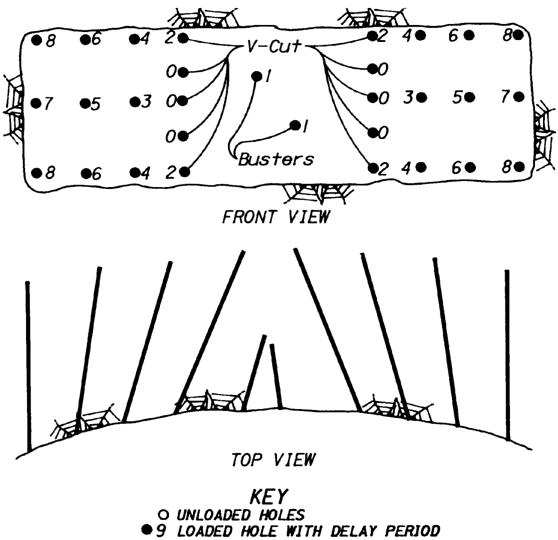

Figure 19-25.—Typical V-cut blast round delay pattern (numbers on loaded holes show delay in milliseconds).

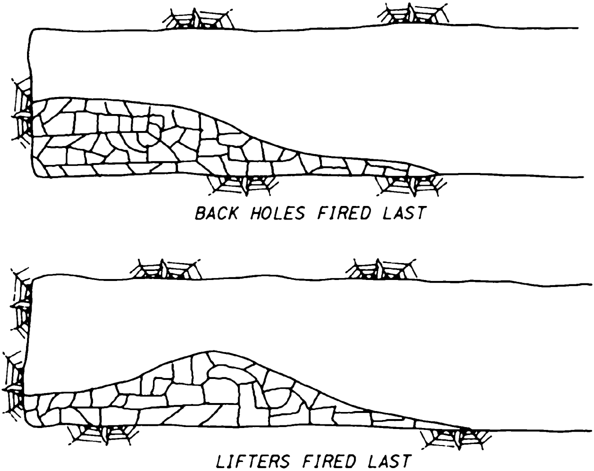

Figure 19-26.—Shape of muckpile as a function of firing order.

12 lb/yd^3 (0.7 to 5.5 kg/m^3). Soft, light weight rock, headings with large cross sections, large blast holes, and angle cut rounds all tend to require lower powder factors than hard, dense rock, small headings, small blast holes, and parallel hole cuts.

Controlled Blasting Techniques

The term, controlled blasting, is used to describe several techniques that limit damage to the rock at the perimeter of the excavation by preventing the force of a blast from continuing into the side walls. Normal blasting propagates cracks into the surrounding rock. These cracks can reduce the stability of the opening. The purpose of controlled blasting is to reduce this perimeter cracking and, thus, increase stability of the final surface. Much of the following discussion on controlled blasting techniques has been determined through years of on-the-job testing and evaluation. The results of controlled blasting are a function of the geology, especially the number and orientation of joint and fracture planes and the quality of the final rock surface that is required.

Line Drilling

Line drilling consists of drilling a row of closely spaced holes along the final excavation limits and not loading the holes with explosive. The line-drilled holes provide a plane of weakness to which the final row of blast holes can break and also reflect a portion of the blast's shock wave. Line drilling is used mostly in small blasting operations and involves small holes in the range of 2 to 3 inches (50-75 mm) in diameter. Line drilling holes are spaced (center to center) two to four diameters apart but are more closely spaced at the corners. The maximum practical depth to which line drilling can be done is governed by how accurately the alignment of the holes can be held at depth (seldom more than 30 feet [10 m]).

To further protect the final perimeter, the blast holes adjacent to the line drill are spaced more closely and loaded more lightly than the rest of the blast, and deck charges are used as necessary. Best results are obtained in a homogeneous rock with few joints or bedding planes or when the holes are aligned with a major joint plane. Line drilling is sometimes used in conjunction with presplitting where the corners are line drilled and the remainder of the perimeter is presplit.

The use of line drilling is limited to jobs where even a light load of explosives in the perimeter holes would cause unacceptable damage. The results of line drilling are often unpredictable, the cost of drilling is high, and the results depend on the accuracy of the drilling.

Presplitting

Presplitting, sometimes called preshearing, is similar to line drilling except that the holes are drilled slightly farther apart and are loaded very lightly. Presplit holes are fired before any of the adjacent main blast holes. The light explosive charges propagate a crack between the holes. In badly fractured rock, unloaded guide holes may be drilled between the loaded holes. The light powder load may be obtained by using specially designed slender cartridges, partial or whole cartridges taped to a detonating cord downline, an explosive cut from a continuous reel, or heavy grain detonating cord. A heavier charge of tamped cartridges is used in the bottom few feet of hole. Figure 19-27 shows three types of blast hole loads used for presplitting. Cartridges ¾ or ⅞ inch by 2 feet (19 or 22 mm by 0.6 m) connected with couplers are available. Manufacturers now produce continuous, small diameter, long-tubular water gel columns for loading presplit holes. The diameter of these continuous tubular columns usually is 1 inch (25 mm), and they come with a built-in downline. They can be loaded easily in rough and inclined holes. The continuous column presplit explosives produce increased loading rates and reduced labor costs.

If possible, stem completely around and between the cartridges in the blast hole; and, although not essential, fire in advance of the main blast. The maximum depth for a single presplit is limited by the accuracy of the drillholes and is usually about 50 feet (15 m). Depths between 20 and 40 feet (6 and 12 m) are recommended. A deviation of greater than 6 inches (152 mm) from the desired plane or shear will give inferior results. Avoid presplitting too

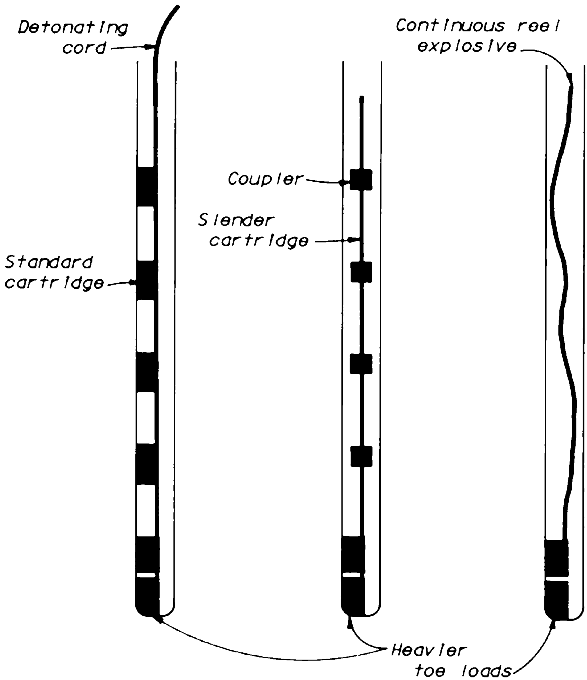

Figure 19-27.—Typical presplit blast hole loading.

far ahead of the production blast. If possible, presplit a short section and dig that section out so that the quality of the presplit can be checked. If the presplit results are unsatisfactory, adjustments can be made in subsequent blasts.

Presplitting is usually done in a separate operation and well in advance of drilling and loading the main blast. The presplit holes can be fired with the main blast by firing the presplit holes on the first delay period. The increased hole spacing compared with line drilling reduces drilling costs. Table 19-4 gives parameters for presplitting.

Smooth Blasting

Smooth blasting, also called contour blasting, perimeter blasting, or sculpture blasting, is the most widely used method of controlling overbreak in underground openings such as drifts and stopes (benches). Smooth blasting is similar to presplitting in that an additional row of holes is drilled at the perimeter of the excavation. These holes contain light loads and are more closely spaced than the other holes in the round (figure19-28). The light powder load usually is continuously "string loaded" (loaded end to end) with slender cartridges or continuous reel explosive is used as shown in figure 19-27. Unlike presplitting, the smooth blast holes are fired after the main blast. Usually, this is done by loading and connecting the entire round and firing the perimeter holes one delay later than the last hole in the round. The burden on the perimeter holes should be approximately 1.5 times the spacing. Table 19-5 gives parameters for smooth blasting.

A compromise for smooth wall blasting is to slightly reduce the spacing of the perimeter holes, compared to a standard design, and "string load" regular cartridges of explosive. The explosive column should be sealed with a tamping plug, clay plug, or other type of stemming to prevent the string-loaded charges from being extracted from the hole by charges on earlier delays. Smooth blasting reduces overbreak and reduces the need for ground support. These advantages usually outweigh the cost of the additional perimeter holes.

Table 19-4.—Parameters for presplitting

Hole diameter		Spacing		Explosive charge	
(inch)	(mm)	(feet)	(m)	(lb/ft)	(kg/m)
1.50-1.75	38-44	1.00-1.50	0.3-0.46	0.08-0.25	0.03-0.1
2.00-2.50	50-64	1.50-2.00	0.46-0.6	.08-0.25	0.03-0.1
3.00-3.50	75-90	1.50-3.00	0.6-1.0	0.13-0.50	0.05-0.23
4.00	100	2.00-4.00	0.6-1.2	0.25-0.75	0.23-0.34

Table 19-5.—Parameters for smooth blasting

Hole diameter		Spacing		Burden		Explosive charge	
(inch)	(mm)	(feet)	(m)	(feet)	(m)	(lb/ft)	(kg/m)
1.50-1.75	38-44	2.00	0.6	3.00	1	0.12-0.25	0.05-0.55
2.0	50	2.50	0.75	3.50	1.06	0.12-0.25	0.05-0.55

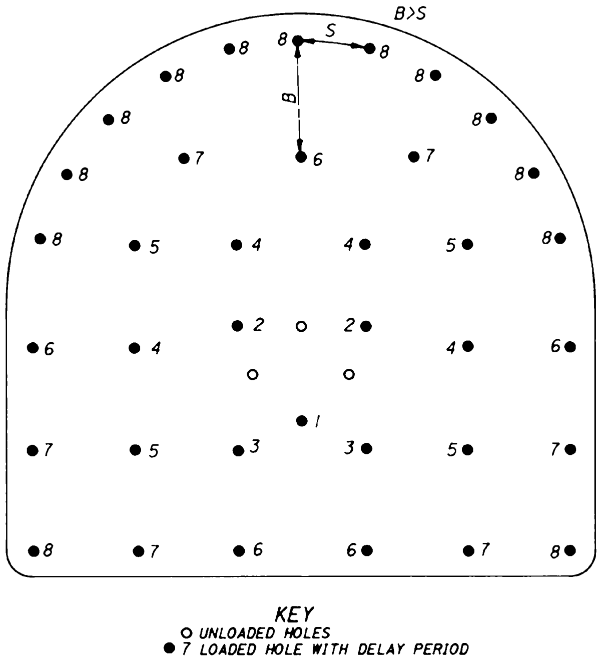

Figure 19-28.—Typical smooth blasting pattern (Burden, B, is larger than spacing, S). Numbers on holes show delay in milliseconds.

Cushion Blasting

Cushion blasting, also called trimming, slabbing, or slashing, is the surface equivalent of smooth blasting. Like other controlled blasting techniques, cushion blasting involves a row of closely spaced, lightly loaded holes at the perimeter of the excavation. Holes up to

6½ inches (165 mm) in diameter have been used in cushion blasting. Drilling accuracy with this larger size borehole permits depths of up to 90 feet (27 m) for cushion blasting. After the explosives have been loaded, stemming is placed in the void space around the charges for the entire length of the column. Stemming "cushions" the shock from the finished wall minimizing the stresses and fractures in the finished wall. The cushion blast holes are fired after the main excavation is removed (figure19-29). A minimum delay between the cushion blast holes is

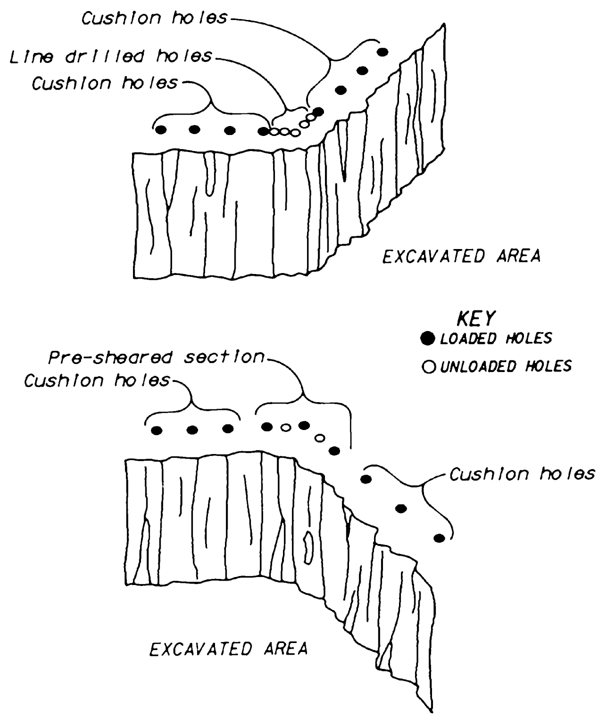

Figure 19-29.—Cushion blasting techniques.

desirable. The same loading techniques that apply to presplitting are used with cushion blasting. The burden on the cushion holes should always be less than the width of the berm being removed.

The large diameter holes associated with cushion blasting result in larger spacings as compared with presplitting reducing drilling costs. Better results can be obtained in poorly lithified and weathered formations than with presplitting, and the larger holes permit better alignment at depth. Table 19-6 gives parameters for cushion blasting.

Riprap Blasting Techniques

Riprap blasting follows the usual rules for blast designs. A few special techniques can aid production of quality riprap.

Powder distribution is the key to satisfactory results. If the above principles of good blast design are followed, satisfactory results should be achieved. The blast design must be monitored continually and changed to produce the best results.

Full column loading is usually the best for initial shots. The starting burden for riprap production should be larger than predicted from table 19-1. If a burden of 7 feet (2.1 m) is predicted, a starting burden of approximately 9 feet (2.7 m) should be tried. Further adjustments can be made to optimize the breakage.

In typical quarry blasting, a spacing of 1.5 times the burden is a good first estimate. The spacing should be about equal to the burden but not smaller than the burden for riprap. Either a square or a staggered drill

Table 19-6.—Parameters for cushion blasting

Hole diameter		Spacing		Burden		Explosive charge	
(inch)	(mm)	(feet)	(m)	(feet)	(m)	(lb/ft)	(kg/m)
2.00-2.50	50-64	3.00	1.0	4.00	1.2	0.08-0.25	0.03-0.1
3.00-3.50	75-90	4.00	1.2	5.00	1.5	0.13-0.5	0.05-0.2
4.00-4.50	100-115	5.00	1.5	6.00	1.8	0.25-0.75	0.1-0.3
5.00-5.50	127-140	6.00	1.8	7.00	2.1	0.75-1.00	0.3-0.45
6.00-6.50	152-165	7.00	2.1	9.00	2.7	1.00-1.50	0.45-0.7

pattern should be used. The square pattern often gives a coarser product but also may give more erratic toe conditions. Where possible, rows of blast holes should be perpendicular to the major vertical plane of weakness such as the primary vertical joint set.

If a reasonably well graded riprap is specified, it will be necessary to perform test or trial blasts. The product should be analyzed for gradation, and further test blasts made and gradations checked until the specifications have been met. If insufficient coarse product is produced, the burden and spacing of subsequent rounds should be increased by 1 foot (0.3 m) per round until the amount of coarse product is adequate. If toe problems occur before the amount of coarse product is adequate, reduce the burden and spacing again and increase the stemming or try deck loading in the upper part of the lift.

If too much coarse product is produced, determine whether the material comes from the top or bottom part of the bench face. If the material comes from the bottom or is generally well-distributed, decrease the burden and spacing in 1-foot (0.3-m) increments until the oversize is controlled. If the oversize comes from the top, try using satellite holes (short, smaller diameter holes between the main blast holes, figure19-4) or less stemming.

It is essential that each blast be laid out accurately and drilled and loaded so that there is a known baseline to adjust from if early results are not good. Keeping good records is essential for later adjustments to the blast design. Single row firing, at least for the early shots, also simplifies blast pattern adjustments.

In dry conditions, ANFO will work well. A good, fast, bottom primer should be used. In wet conditions, an emulsion, water gel, slurry, or gelatin dynamite should be used. The bottom of the blast hole should be primed. Excessive orange smoke from a blast indicates the need for a water resistant product or for a better proportional mix of the ANFO.

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Glossary

A

Acoustical impedance - The mathematical expression characterizing a material energy transfer property. The product of a material unit density and sonic velocity.

Adobe charge - See mud cap.

Airblast - An airborne shock wave resulting from the detonation of explosives; may be caused by burden movement or the release of expanding gas into the air. Airblast may or may not be audible.

Airdox - System that uses 10,000 lb/in^2 compressed air to break undercut coal. Airdox will not ignite a gassy or dusty atmosphere.

Aluminum - A metal commonly used as a fuel or sensitizing agent in explosives and blasting agents; normally used in finely divided particle or flake form.

American Table of Distance - A quantity-distance table published by the Institute of Makers of Explosives (IME) as pamphlet No. 2, which specifies safe explosive storage distances from inhabited buildings, public highways, passenger railways, and other stored explosive materials.

Ammonium nitrate (AN) - The most commonly used oxidizer in explosives and blasting agents, NH_4NO_3.

ANFO - An explosive material consisting of a mixture of ammonium nitrate and fuel oil. The most commonly used blasting agent.

ATF - Bureau of Alcohol, Tobacco and Firearms, U.S. Department of the Treasury, which enforces explosives control and security regulations.

Axial priming - A system for priming blasting agents where a core of priming materials extends through most or all of the blasting agent charge length.

B

Back break - Rock broken beyond the limits of the last row of holes.

Back holes - The top holes in a tunnel or drift round.

Base charge - The main explosive charge in a detonator.

Bench - The horizontal ledge in a quarry face along where holes are drilled. Benching is the process of excavating where terraces or ledges are worked in a stepped sequence.

Binary explosive - An explosive based on two nonexplosive ingredients, such as nitromethane and ammonium nitrate. Materials are shipped and stored separately and mixed at the jobsite to form a high explosive.

Black powder - A low energy explosive consisting of sodium or potassium nitrate, carbon, and sulfur. Black powder is seldom used today because of the low energy, poor fume quality, and extreme sensitivity to sparks.

Blast - The detonation of explosives to break rock.

Blast area - The area near a blast within the influence of flying rock or concussion.

Blaster - A qualified person in charge of a blast. Also, a person (blaster-in-charge) who has passed test approved by Office of Surface Mining (OSM) which certifies the blaster's qualifications to supervise blasting activities.

Blasters' galvanometer - Blasters' multimeter; see galvanometer, multimeter.

Blast hole - A hole drilled in rock or other material for the placement of explosives.

Blasting agent - An explosive that meets prescribed criteria for insensitivity to initiation. For storage, any material or mixture consisting of a fuel and oxidizer, intended for blasting, not otherwise defined as an explosive, provided that the finished product, as mixed and packaged for use or shipment, cannot be detonated by means of a No. 8 test blasting cap when unconfined (ATF). For transportation, a material designed for blasting that has been tested in accordance with the Code of Federal Regulations (CFR) Title 49, Section 173.14a, and found to be so insensitive that there is very little probability of accidental initiation to explosion or transition from deflagration to detonation (Department of Transportation [DOT]).

Blasting cap - A detonator that is initiated by safety fuse (Mine Safety and Health Administration [MSHA]). See detonator.

Blasting circuit - The circuit used to fire one or more blasting caps.

Blasting crew - A crew whose job is to load explosive charges.

Blasting machine - Any machine built expressly for the purpose of energizing blasting caps or other types of initiators.

Blasting mat - See mat.

Blasting switch - A switch used to connect a power source to a blasting circuit.

Blistering - See mud cap.

Blockhole - A hole drilled into a boulder to allow the placement of a small charge to break the boulder.

Booster - A unit of explosive or blasting agent used for perpetuating or intensifying an explosive reaction. A booster does not contain an initiating device but is often cap sensitive.

Bootleg - That portion of a borehole that remains relatively intact after having been charged with explosive and fired. A bootleg may contain unfired explosive and may be hazardous.

Borehole (blast hole) - A drilled hole, usually in rock, that is loaded with explosives.

Borehole pressure - The pressure that the hot gases of detonation exert on the borehole wall. Borehole pressure is primarily a function of the density of the explosive and the heat of explosion.

Bridge wire - A very fine filament wire imbedded in the ignition element of an electric blasting cap. An electric current passing through the wire causes a sudden heat rise, causing the ignition element to be ignited.

Brisance - A property of an explosive roughly equivalent to detonation velocity. An explosive with a high detonation velocity has high brisance.

Bubble energy - The expanding gas energy of an explosive, as measured in an underwater test.

Bulk mix - An explosive material prepared for use without packaging.

Bulk strength - The strength of an explosive per unit volume.

Bulldoze - See mud cap.

Burden - The distance to the nearest free or open face from an explosive charge. There may be apparent burden and a true burden, the latter being measured in the direction broken rock will be displaced following firing of the explosive charge. Also, the amount of material to be blasted by a given hole in tons or cubic yards (m^3).

Burn cut - A parallel hole cut employing several closely spaced blast holes. Not all of the holes are loaded with explosive. The cut creates a cylindrical opening by shattering the rock.

Bus wires - The two wires joined to the connecting wire where the leg wires of the electric caps are connected in a parallel circuit. Each leg wire of each cap is connected to a different bus wire. In a series-in-parallel circuit, each end of each series is connected to a different bus wire.

Butt - See bootleg.

C

Cap - See detonator.

Capped fuse - A length of safety fuse with an attached blasting cap.

Capped primer - A package or cartridge of cap-sensitive explosive that is specifically designed to transmit detonation to other explosives and which contains a detonator (MSHA).

Cap sensitivity - The sensitivity of an explosive to initiation, relative to an IME No. 8 test detonator.

Carbon monoxide - A poisonous gas created by detonating explosive materials. Excessive carbon monoxide is caused by an inadequate amount of oxygen in the explosive mixture (excessive fuel).

Cardox - A system that uses a cartridge filled with liquid carbon dioxide, which when initiated by a mixture of potassium perchlorate and charcoal, creates a pressure adequate to break undercut coal.

Cartridge - A rigid or semirigid container of explosive or blasting agent of a specified length or diameter.

Cartridge count - The number of 1¼- by 8-inch (32- by 203-mm) cartridges of explosives per 50-pound (22.7-kg) case.

Cartridge strength - A rating that compares a given volume of explosive with an equivalent volume of straight nitroglycerin dynamite expressed as a percentage.

Cast primer - A cast unit of explosive, usually pentolite or composition B, commonly used to initiate detonation in a blasting agent.

Chambering - The process of enlarging a portion of blast hole (usually the bottom) by firing a series of small explosive charges. Chambering can also be done by mechanical or thermal methods.

Chapman-Jougeut (C-J) plane - The plane that defines the rear boundary of the primary reaction zone in a detonating explosive column.

Circuit tester - See galvanometer or multimeter.

Class A explosive - Defined by the U.S. Department of Transportation (DOT) as an explosive that possesses detonating or otherwise maximum hazard; such as, but not limited to, dynamite, nitroglycerin, lead azide, black powder, blasting caps, and detonating primers.

Class B explosive - Defined by DOT as an explosive that possesses flammable hazard, such as, but not limited to, propellant explosives, photographic flash powders, and some special fireworks.

Class C explosive - Defined by DOT as an explosive that contains Class A or Class B explosives, or both, as components but in restricted quantities. For example, blasting caps or electric blasting caps in lots of less than 1,000.

Collar - The top or opening of a borehole or shaft. To "collar" in drilling means the act of starting a borehole.

Collar distance - The distance from the top of the powder column to the collar of the blast hole, usually filled with stemming.

Column charge - A long, continuous charge of explosive or blasting agent in a borehole.

Commercial explosives - Explosives designed and used for commercial or industrial, rather than military applications.

Composition B - A mixture of RDX and TNT that has a density of 1.65 g/cm^3 and a velocity of 25,000 feet per second (7,622 m/sec), when cast. It is useful as a primer for blasting agents.

Condenser-discharge blasting machine - A blasting machine that uses batteries or magnets to energize one or more condensers (capacitors) whose stored energy is released into a blasting circuit.

Confined detonation velocity - The detonation velocity of an explosive or blasting agent under confinement such as in a borehole.

Connecting wire - A wire, smaller in gage than the lead wire, used in a blasting circuit to connect the cap circuit with the lead wire or to extend leg wires from one borehole to another. Usually considered expendable.

Connector - See MS connector.

Controlled blasting - Techniques used to control overbreak and produce a competent final excavation wall. See line drilling, presplitting, smooth blasting, and cushion blasting.

Cordeau detonant fuse - A term used to define detonating cord.

Cornish cut - See parallel hole cut.

Coromant cut - See parallel hole cut.

Coupling - The degree that an explosive fills the borehole. Untamped cartridges are decoupled; also capacitive and inductive coupling from power lines to an electric blasting circuit.

Coyote blasting - The practice of driving tunnels horizontally into a rock face at the foot of the shot. Explosives are loaded into these tunnels. Coyote blasting is used where it is impractical to drill vertically.

Critical diameter - The minimum diameter of any explosive for propagation of a stable detonation. Critical diameter is effected by confinement, temperature, and pressure on the explosive.

Crosslinking agent - The final ingredient added to a water gel or slurry, causing the material to change from a liquid to a gel.

Current limiting device - A device used to prevent arcing in electric blasting caps by limiting the amount or duration of current flow. Also used in a blasters' galvanometer or multimeter to ensure a safe current output.

Cushion blasting - A surface blasting technique used to produce competent slopes. The cushion holes, fired after the main charge, have a reduced spacing and employ decoupled charges.

Cushion stick - A cartridge of explosive loaded into a small diameter borehole before the primer. The use of a cushion stick is not generally recommended because of possible bootlegs.

Cut - An arrangement of holes used in underground mining and tunnel blasting providing a free face for the remainder of the round to break.

Cutoffs - A portion of a column of explosives that has failed to detonate owing to bridging or a shifting of the rock formation, often due to an improper delay system; also a cessation of detonation in detonating cord.

D

Dead pressing - Desensitization of an explosive caused by pressurization. Tiny air bubbles required for sensitivity are literally squeezed from the mixture.

Decibel - The unit of sound pressure commonly used to measure airblast from explosives. The decibel scale is logarithmic.

Deck - A small charge or portion of a blast hole loaded with explosives that is separated from other charges by stemming or an air cushion.

Decoupling - The use of cartridged products significantly smaller in diameter than the borehole. Decoupled charges are normally not used except in cushion blasting, smooth blasting, presplitting, and other situations where crushing is undesirable.

Deflagration - A subsonic but extremely rapid explosive reaction accompanied by gas formation and borehole pressure but without shock.

Delay blasting - The use of delay detonators or connectors that cause separate charges to detonate at different times rather than simultaneously.

Delay connector - A nonelectric, short-interval delay device for use in delaying blasts that are initiated by detonating cord.

Delay detonator - An electric or nonelectric detonator with a built-in element that creates a delay between the input of energy and the explosion of the detonator.

Delay electric blasting cap - An electric blasting cap with a built-in delay that delays cap detonation in predetermined time intervals from milliseconds up to a second or more.

Delay element - The portion of a blasting cap that causes a delay between the application of energy to the cap and the time of detonation of the base charge of the cap.

Density - The weight per unit volume of explosive, expressed as cartridge count or grams per cubic centimeter. See loading density.

Department of Transportation (DOT) - A Federal agency that regulates safety in interstate shipping of explosives and other hazardous materials.

Detaline System - A nonelectric system for initiating blasting caps where the energy is transmitted through the circuit by a low-energy detonating cord.

Detonating cord - A plastic covered core of high-velocity explosive, usually PETN, used to detonate explosives. The plastic covering is covered with various combinations of textiles and waterproofing.

Detonation - A supersonic explosive reaction where a shock wave propagates through the explosive accompanied by a chemical reaction that furnishes energy to sustain stable shock wave propagation. Detonation creates both a detonation pressure and a borehole pressure.

Detonation pressure - The head-on pressure created by the detonation proceeding down the explosive column. Detonation pressure is a function of the explosive density and the square of the explosive velocity.

Detonation velocity - See velocity.

Detonator - Any device containing a detonating charge that is used to initiate an explosive. Includes, but is not limited to, blasting caps, electric blasting caps, and nonelectric instantaneous or delay blasting caps.

Ditch blasting - See propagation blasting.

DOT - See Department of Transportation.

Downline - The line of detonating cord in the borehole that transmits energy from the trunkline down the hole to the primer.

Drilling pattern - See pattern.

Drop ball - Known also as a headache ball. An iron or steel weight held on a wire rope that is dropped from a height onto large boulders to break them into smaller fragments.

Dynamite - The high explosive invented by Alfred Nobel. Any high explosive where the sensitizer is nitroglycerin or a similar explosive oil.

E

Echelon pattern - A delay pattern that causes the true burden at the time of detonation to be at an oblique angle from the original free face.

Electric blasting cap - A blasting cap designed to be initiated by an electric current.

Electric storm - An atmospheric disturbance of intense electrical activity presenting a hazard in all blasting activities.

Emulsion - An explosive material containing substantial amounts of oxidizers dissolved in water droplets surrounded by an immiscible fuel. Similar to a slurry.

Exploding bridge wire (EBW) - A wire that explodes upon application of current. The wire takes the place of the primary explosive in an electric detonator. An exploding bridge wire detonator is an electric detonator that employs an exploding bridge wire rather than a primary explosive. An exploding bridge wire detonator is instantaneous.

Explosion - A thermochemical process where mixtures of gases, solids, or liquids react with the almost instantaneous formation of gas pressures and sudden heat release.

Explosion pressure - See borehole pressure.

Explosive - Any chemical mixture that reacts at high velocity to liberate gas and heat causing very high pressures. ATF classifications include high explosives and low explosives. Also, any substance classified as an explosive by DOT.

Explosive materials - A term that includes, but is not necessarily limited to, dynamite and other high explosives, slurries, water gels, emulsions, blasting agents, black powder, pellet powder, initiating explosives, detonators, safety fuses, squibs, detonating cord, igniter cord, and igniters.

Extra dynamite - Also called ammonia dynamite, a dynamite that derives the major portion of its energy from ammonium nitrate.

Extraneous electricity - Electrical energy other than actual firing current that may be a hazard with electric blasting caps. Includes stray current, static electricity, lightning, radio frequency energy, and capacitive or inductive coupling.

F

Face - A rock surface exposed to air. Also called a free face, a face provides the rock with room to expand upon fragmentation.

Firing current - Electric current purposely introduced into a blasting circuit for initiation. Also, the amount of current required to activate an electric blasting cap.

Firing line - A line, often permanent, extending from the firing location to the electric blasting cap circuit. Also called lead wire.

Flash over - Sympathetic detonation between explosive charges or between charged blast holes.

Flyrock - Rock that is propelled through the air from a blast. Excessive flyrock may be caused by poor blast design or unexpected weak zones in the rock.

Fracturing - The breaking of rock with or without movement of the broken pieces.

Fragmentation - The extent that a rock is broken into pieces by blasting. Also the act of breaking rock.

Fuel - An ingredient in an explosive that reacts with an oxidizer to form gaseous products of detonation.

Fuel oil - The fuel in ANFO, usually No. 2 diesel.

Fume Classification - An IME quantification of the amount of fumes generated by an explosive or blasting agent.

Fume quality - A measure of the toxic fumes to be expected when a specific explosive is properly detonated. See fumes.

Fumes - Noxious or poisonous gases liberated from a blast. May be due to a low fume quality explosive or inefficient detonation.

Fuse - See safety fuse.

Fuse lighter - A pyrotechnic device for rapid and dependable lighting of safety fuse.

G

Galvanometer - (More properly called blasters' galvanometer.) A measuring instrument containing a silver chloride cell and/or a current limiting device that is used to measure resistance in an electric blasting circuit. Only a device specifically identified as a blasting galvanometer or blasting multimeter should be used for this purpose.

Gap sensitivity - The gap distance an explosive can propagate across. The gap may be air or a defined solid material. Gap sensitivity is a measure of the likelihood of sympathetic propagation.

Gas detonation system - A system for initiating caps where the energy is transmitted through the circuit by a gas detonation inside a hollow plastic tube.

Gelatin - An explosive or blasting agent that has a gelatinous consistency. The term is usually applied to a gelatin dynamite but may also be a water gel.

Gelatin dynamite - A highly water-resistant dynamite with a gelatinous consistency.

Generator blasting machine - A blasting machine operated by vigorously pushing down a rack bar or twisting a handle. Now largely replaced by condensor discharge blasting machines.

Grains - A weight measurement unit where 7,000 grains equal 1 pound.

Ground vibration - Ground shaking caused by the elastic wave emanating from a blast. Excessive vibrations may cause damage to structures.

H

Hangfire - The detonation of an explosive charge after the designed firing time. A source of serious accidents.

Heading - The working face or end of an excavation driven in an underground mine.

Hercudet - See gas detonation system.

Hertz - A term used to express the frequency of ground vibrations and airblast. One hertz is one cycle per second.

High explosive - Any product used in blasting that is sensitive to a No. 8 test blasting cap and reacts at a speed faster than that of sound in the explosive medium. A classification used by ATF for explosive storage.

Highwall - The bench, bluff, or ledge on the edge of a surface excavation. This term is most commonly used in coal strip mining.

I

Ignitacord – A cordlike fuse that burns progressively along its length with an external flame at the zone of burning and is used for lighting a series of safety fuses in sequence. Burns with a spitting flame similar to a Fourth-of-July sparkler.

IME - The Institute of Makers of Explosives. A trade organization dealing with the use of explosives and concerned with safety in manufacture, transportation, storage, handling, and use. The IME publishes a series of blasting safety pamphlets.

Initiation - The act of detonating a high explosive by means of a cap, mechanical device, or other means. Also the act of detonating the initiator.

Instantaneous detonator - A detonator that contains no delay element.

J

Jet 1oader - A system for loading ANFO into small blastholes where the ANFO is sucked from a container and blown into the hole at high velocity through a loading hose.

Jumbo - A machine designed to mount two or more drilling units that may or may not be operated independently.

K

Kerf - A slot cut in a coal or soft rock face by a mechanical cutter to provide a free face for blasting.

L

Lead wire - The wire connecting the electrical power source with the leg wires or connecting wires of a blasting circuit. Also called a firing line.

LEDC - Low-energy detonating cord used to initiate nonelectric blasting caps.

Leg wires - Wires connected to the bridge wire of an electric blasting cap and extending from the waterproof plug. The opposite ends are used to connect the cap into a circuit.

Lifters - The bottom holes in a tunnel or drift round.

Line drilling - An overbreak control method where a series of very closely spaced holes are drilled at the perimeter of the excavation. These holes are not loaded with explosive.

Liquid oxygen explosive - A high explosive made by soaking cartridges of carbonaceous materials in liquid oxygen. This explosive is rarely used today.

Loading density - The pounds of explosive per foot of charge of a specific diameter.

Loading factor - See powder factor.

Loading pole - A pole made of nonsparking material used to push explosive cartridges into a borehole and to break and tightly pack the explosive cartridges into the hole.

Low explosive - An explosive where the speed of reaction is slower than the speed of sound, such as black powder. A classification used by ATF for explosive storage.

LOX - See liquid oxygen explosive.

M

Magazine - A building, structure, or container specially constructed for storing explosives, blasting agents, detonators, or other explosive materials.

Mat - A covering placed over a shot to hold down flying material. The mat is usually made of woven wire cable, rope, or scrap tires.

Maximum firing current - The highest current (amperage) recommended for the safe and effective initiation of an electric blasting cap.

Metallized - Sensitized or energized with finely divided metal flakes, powders, or granules, usually aluminum.

Michigan cut - See parallel hole cut.

Microballoons - Tiny hollow spheres of glass or plastic that are added to explosive materials to enhance sensitivity by assuring adequate entrapped air content.

Millisecond (ms) - Short delay intervals equal to 1/1,000 of a second.

Millisecond delay caps - Delay detonators that have built-in time delays of various lengths. The interval between the delays at the lower end of the series is usually 25 ms. The interval between delays at the upper end of the series may be 100 to 300 ms.

Minimum firing current - The lowest current (amperage) that will initiate an electric blasting cap within a specified short interval of time.

Misfire - A charge or part of a charge that has failed to fire as planned. All misfires are dangerous.

Monomethylaminenitrate - A compound used to sensitize some water gels.

MS connector - A device used as a delay in a detonating cord circuit connecting one hole in the circuit with another or one row of holes to other rows of holes.

MSHA - The Mine Safety and Health Administration. An agency under the Department of Labor that enforces health and safety regulations in the mining industry.

Muckpile - A pile of broken rock or dirt that is to be loaded for removal.

Mud cap - Referred to also as adobe, bulldoze, blistering, or plaster shot. A charge of explosive fired in contact with the surface of a rock usually covered with a quantity of mud, wet earth, or similar substance. No borehole is used.

Multimeter - A multipurpose test instrument used to check line voltages, firing currents, current leakage, stray currents, and other measurements pertinent to electric blasting. (More properly called blasters' multimeter.) Only a meter specifically designated as a blasters' multimeter or blasters' galvanometer should be used to test electric blasting circuits.

N

National Fire Protection Association (NFPA) - An industry/government association that publishes standards for explosive material and ammonium nitrate.

Nitrocarbonitrate - A shipping classification once given to a blasting agent by DOT.

Nitrogen oxides - Poisonous gases created by detonating explosive materials. Excessive nitrogen oxides may be caused by an excessive amount of oxygen in the explosive mixture (excessive oxidizer) or by inefficient detonation.

Nitroglycerin (NG) - The explosive oil originally used as the sensitizer in dynamites, $C_3H_5(ONO_2)_3$.

Nitromethane - A liquid compound used as a fuel in two-component (binary) explosives and as rocket and dragster fuel.

Nitropropane - A liquid fuel that can be combined with pulverized ammonium nitrate prills to make a dense blasting mixture.

Nitrostarch - A solid explosive similar to nitroglycerin used as the base of “nonheadache” powders.

Nonel - See shock tube system.

Nonelectric delay blasting cap - A detonator with a delay element capable of being initiated nonelectrically. See shock tube system; gas detonation system; Detaline System.

No. 8 test blasting cap - See test blasting cap No. 8.

O

OSHA - The Occupational Safety and Health Administration. An agency under the Department of Labor that enforces health and safety regulations in the construction industry, including blasting.

OSM - The Office of Surface Mining Reclamation and Enforcement. An agency under the Department of the Interior that enforces surface environmental regulations in the coal mining industry.

Overbreak - Excessive breakage of rock beyond the desired excavation limit.

Overburden - Worthless material lying on top of a deposit of useful materials. Overburden often refers to dirt or gravel but can be rock, such as shale over limestone or shale and limestone over coal.

Overdrive - Inducing a velocity higher than the steady state velocity in a powder column by the use of a powerful primer. Overdrive is a temporary phenomenon, and the powder quickly assumes its steady state velocity.

Oxides of nitrogen - See nitrogen oxides.

Oxidizer - An ingredient in an explosive or blasting agent that supplies oxygen to combine with the fuel to form gaseous or solid detonation products. Ammonium nitrate is the most common oxidizer used in commercial explosives.

Oxygen balance - A mixture of fuels and oxidizers where the gaseous products of detonation are predominantly carbon dioxide, water vapor (steam), and free nitrogen. A mixture containing excess oxygen has a negative oxygen balance.

P

Parallel circuit - A circuit where two wires, called bus wires, extend from the lead wire. One leg wire from each cap in the circuit is hooked to each of the bus wires.

Parallel hole cut - A group of parallel holes, some of which are loaded with explosives, used to establish a free face in tunnel or heading blasting. One or more of the unloaded holes may be larger than the blast holes; also called Coromant, Cornish, burn, shatter, or Michigan cut.

Parallel series circuit - Similar to a parallel circuit but involving two or more series of electric blasting caps.

One end of each series of caps is connected to each of the bus wires; sometimes called series-in-parallel circuit.

Particle velocity - A measure of ground vibration. Describes the velocity of particle vibration when excited by a seismic wave.

Pattern - A drill hole plan laid out on a face or bench to be drilled for blasting.

Pellet powder - Black powder pressed into 2-inch-long, 1¼- to 2-inch diameter cylindrical pellets.

Pentaerythritoltetranitrate (PETN) - A military explosive compound used as the core load of detonating cord and the base charge of blasting caps.

Pentolite - A mixture of PETN and TNT used as a cast primer.

Permissible - A machine, material, apparatus, or device that has been investigated, tested, and approved by the Bureau of Mines or MSHA maintained in permissible condition.

Permissible blasting - Blasting according to MSHA regulations for underground coal mines or other gassy underground mines.

Permissible explosives - Explosives that have been approved by MSHA for use in underground coal mines or other gassy mines.

PETN - See pentaerythritoltetranitrate.

Plaster shot - See mud cap.

Pneumatic 1oader - One of a variety of machines powered by compressed air used to load bulk blasting agents or cartridged water gels.

Powder - Any solid explosive.

Powder chest - A strong, nonconductive portable container equipped with a lid used at blasting sites for temporary explosive storage.

Powder factor - A ratio between the amount of powder loaded and the amount of rock broken, usually expressed as pounds per ton or pounds per cubic yard. In some cases, the reciprocals of these terms are used.

Preblast survey - A documentation of the existing condition of a structure. The survey is used to determine whether subsequent blasting causes damage to the structure.

Premature - A charge that detonates before intended.

Preshearing - See presplitting.

Presplitting - Controlled blasting where decoupled charges are fired in closely spaced holes at the perimeter of the excavation. A presplit blast is fired before the main blast. Also called preshearing.

Pressure vessel - A system for loading ANFO into small diameter blast holes. The ANFO is contained in a sealed vessel where air pressure forces the ANFO through a hose and into the blast hole; also known as pressure pot.

Prill - A small porous sphere of ammonium nitrate capable of absorbing more than 6 percent by weight of fuel oil. Blasting prills have a bulk density of 0.80 to 0.85 g/cm^3.

Primary blast - The main blast executed to sustain production.

Primary explosive - An explosive or explosive mixture sensitive to spark, flame, impact, or friction used in a detonator to initiate the explosion.

Primer - A unit, package, or cartridge of cap-sensitive explosive used to initiate other explosives or blasting agents and that contains a detonator.

Propagation - The detonation of explosive charges by an impulse from a nearby explosive charge.

Propagation blasting - The use of closely spaced, sensitive charges. The shock from the first charge propagates through the ground, setting off the adjacent charge and so on. Only one detonator is required; primarily used for ditching in damp ground.

Propellant explosive - An explosive that normally deflagrates and is used for propulsion.

Pull - The quantity of rock or length of advance excavated by a blast round.

R

Radio frequency energy - Electrical energy traveling through the air as radio or electromagnetic waves. Under ideal conditions this energy can fire an electric blasting cap. IME Pamphlet No. 20 recommends safe distances from transmitters to electric blasting caps.

Radio frequency transmitter - An electric device, such as a stationary or mobile radio transmitting station, that transmits a radio frequency wave.

RDX - Cyclotrimethylenetrinitramine, an explosive substance used in the manufacture of compositions B, C-3, and C-4. Composition B is useful as a cast primer.

Relievers - In a heading round, holes adjacent to the cut holes, used to expand the opening made by the cut holes.

Rib holes - The holes at the sides of a tunnel or drift round that determine the width of the opening.

Riprap - Coarse rocks used for river bank or dam stabilization to reduce erosion by water flow.

Rotational firing - A delay blasting system where each charge successively displaces its burden into a void created by an explosive detonated on an earlier delay period.

Round - A group or set of blast holes used to produce a unit of advance in underground headings or tunnels.

S

Safety fuse - A core of potassium nitrate black powder, enclosed in a covering of textile and waterproofing, used to initiate a blasting cap or a black powder charge. Safety fuse burns at a continuous, uniform rate.

Scaled distance - A ratio used to predict ground vibrations. Scaled distance equals the distance from the blast to the point of concern in feet divided by the square root of the charge weight of explosive per delay in pounds. When using the equation, the delay period must be at least 9 ms.

Secondary blasting - Using explosives to break boulders or high bottom resulting from the primary blast.

Seismograph - An instrument that measures and may supply a permanent record of earthborne vibrations induced by earthquakes or blasting.

Semiconductive hose - A hose used for pneumatic loading of ANFO that has a minimum electrical resistance of 1,000 ohms per foot, 10,000 ohms total resistance, and a maximum total resistance of 2,000,000 ohms.

Sensitiveness - A measure of an explosive's ability to propagate a detonation.

Sensitivity - A measure of an explosive's susceptibility to detonation by an external impulse such as impact, shock, flame, or friction.

Sensitizer - An ingredient used in explosive compounds to promote greater ease in initiation or propagation of the detonation reaction.

Sequential blasting machine - A series of condenser discharge blasting machines in a single unit that can be activated at various accurately timed intervals following the application of electrical current.

Series circuit - A circuit of electric blasting caps where each leg wire of a cap is connected to a leg wire from the adjacent caps so that the electrical current follows a single path through the entire circuit.

Series-in-parallel circuit - See parallel series circuit.

Shatter cut - See parallel hole cut.

Shock energy - The shattering force of an explosive caused by the detonation wave.

Shock tube system - A system for initiating caps where the energy is transmitted to the cap by a shock wave inside a hollow plastic tube.

Shock wave - A pressure pulse that propagates at supersonic velocity.

Shot - See blast.

Shot firer - Also referred to as the shooter. The person who actually fires a blast. A powderman may charge or load blast holes with explosives but may not fire the blast.

Shunt - A piece of metal or metal foil that short circuits the ends of cap leg wires to prevent stray currents from causing accidental detonation of the cap.

Silver chloride cell - A low-current cell used in a blasting galvanometer and other devices to measure continuity in electric blasting caps and circuits.

Slurry - An aqueous solution of ammonium nitrate, sensitized with a fuel, thickened, and crosslinked to provide a gelatinous consistency. Sometimes called a water gel. DOT may classify a slurry as a Class A explosive, a Class B explosive, or a blasting agent. An explosive or blasting agent containing substantial portions of water (MSHA). See emulsion; water gel.

Smooth blasting - Controlled blasting used underground where a series of closely spaced holes is drilled at the perimeter, loaded with decoupled charges, and fired on the highest delay period of the blast round.

Snake hole - A borehole drilled slightly downward from horizontal into the floor of a quarry face. Also, a hole drilled under a boulder.

Sodium nitrate - An oxidizer used in dynamites and sometimes in blasting agents.

Spacing - The distance between boreholes or charges in a row measured perpendicular to the burden and parallel to the free face of expected rock movement.

Specific gravity - The ratio of the weight of a given volume of any substance to the weight of an equal volume of water.

Spitter cord - See Ignitacord.

Springing - See chambering.

Square pattern - A blast hole pattern where the holes in succeeding rows are drilled directly behind the holes in the front row. In a truly square pattern, the burden and spacing are equal.

Squib - A firing device that burns with a flash. Used to ignite black powder or pellet powder.

Stability - The ability of an explosive material to maintain its physical and chemical properties over a period of time in storage.

Staggered pattern - A blast hole pattern where the holes in each row are drilled between the holes in the preceding row.

Static electricity - Electrical energy stored on a person or object in a manner similar to that of a capacitor. Static electricity may be discharged into electrical initiators, detonating them.

Steady state velocity - The characteristic velocity at which a specific explosive, under specific conditions in a given charge diameter, will detonate.

Stemming - The inert material such as drill cuttings used in the collar portion (or elsewhere) of a blast hole to confine the gaseous products of detonation; also, the length of blast hole left uncharged.

Stick count - See cartridge count.

Stray current - Current flowing outside the desired conductor. Stray current may come from electrical equipment, electrified fences, electric railways, or similar sources. Flow is facilitated by conductive paths such as pipelines and wet ground or other wet materials. Galvanic action of two dissimilar metals in contact or connected by a conductor may cause stray current.

Strength - An explosive property described variously as cartridge or weight strength, seismic strength, shock or bubble energy, crater strength, or ballistic mortar strength. Not a well-defined property. Used to express an explosive's capacity to do work.

String 1oading - Loading cartridges end-to-end in a borehole without deforming them. Used mainly in controlled blasting and permissible blasting.

Subdrill - To drill blast holes beyond the planned grade lines or below floor level to insure breakage to the planned grade or floor level.

Subsonic - Slower than the speed of sound.

Supersonic - Faster than the speed of sound.

Swell factor - The ratio of the volume of a material in an undisturbed state to that when broken. May also be expressed as the reciprocal of this number.

Sympathetic propagation (sympathetic detonation) - Detonation of an explosive material by an impulse from another detonation through air, earth, or water.

T

Tamping - Compressing the stemming or explosive in a blast hole. Sometimes used synonymously with stemming.

Tamping bag - A cylindrical bag containing stemming material used to confine explosive charges in boreholes.

Tamping pole - See loading pole.

Test blasting cap No. 8 - A detonator containing 0.40 to 0.45 g of PETN base charge at a specific gravity of 1.4 g/cm^3 primed with standard weights of primer, depending on the manufacturer.

Toe - The burden or distance between the bottom of a borehole and the vertical free face of a bench in an excavation. Also the rock left unbroken at the foot of a quarry blast.

Transient velocity - A velocity different from the steady state velocity that a primer imparts to a column of powder. The powder column quickly attains steady state velocity.

Trinitrotoluene (TNT) - A military explosive compound used industrially as a sensitizer for slurries and as an ingredient in pentolite and composition B. Once used as a free-running pelletized powder.

Trunkline -A detonating cord line used to connect the downlines of other detonating cord lines in a blast pattern. Usually runs along each row of blast holes.

Tunnel - A basically horizontal underground passage.

Two-component explosive - See binary explosive.

U

Unconfined detonation velocity - The detonation velocity of an explosive material not confined by a borehole or other confining medium.

V

V-cut - A cut employing several pairs of angled holes meeting at the bottoms used to create free faces for the rest of the blast round.

Velocity - The rate that the detonation wave travels through an explosive. May be measured confined or unconfined. Manufacturer's data are sometimes measured with explosives confined in a steel pipe.

Venturi 1oader - See jet loader.

Volume strength - See cartridge strength or bulk strength.

W

Water gel - An aqueous solution of ammonium nitrate, sensitized with a fuel, thickened, and crosslinked to provide a gelatinous consistency; also called a slurry; may be an explosive or a blasting agent.

Water stemming bags - Plastic bags containing a self-sealing device that are filled with water. Classified as a permissible stemming device by MSHA.

Weight strength - A rating that compares the strength of a given weight of explosive with an equivalent weight of straight nitroglycerin dynamite or other explosive standard, expressed as a percentage.