Chapter 9
GENERAL
ROCK REMOVAL

A MATTER OF SCALE

Nearly all of the research and technical design data available to the blaster has come from large-scale industrial applications (quarrying, mining, and highway construction). One result is that most blaster's guides, including this one, tend to discuss hole diameters, depths, burdens, and spacing distances that are completely foreign to the small-scale blaster. However, the blast design principles and techniques that work for six-inch holes, 50 feet deep, also work for 1.5-inch holes that are six feet deep. It is simply a matter of scale, and the blaster will find that the hole diameter (i.e., the limit on explosive load per foot of borehole) is the pivotal factor from which the rest of the blast design evolves.

PRINCIPLES OF DRILLING

Before addressing the field of explosives engineering, an area of major importance must be examined. This subject is the preparation of the shot area, better known as “drilling the holes in the rock.” Any explosive engineer, blaster, shot-firer, or hole-loader will tell you that the shot can be only as good as the drilling allows. It is extremely important that the holes are drilled where they will do the most good, not just for the convenience of the driller. The best explosive engineer can not make up for improperly drilled holes.

The common drill systems used today are rotary, percussive, and rotary-percussive systems.

Drill bits may be classified by the shape of the cutting surface. Forces are transmitted to the rock, through the bit, and to the cutting surface. The stresses at the contact, as well as underneath the rock, break it. The rock fails in three ways: *crushing, chipping, and spalling.*

The blaster must analyze the mechanics of a drilling system to reveal the limitations and advantages for each type of rock. For example, a rock with a high compressive strength is likely to respond well to the crushing and chipping action of the percussive bit. On the other hand, a relatively weakly bonded rock may not respond much better to percussive action, but will give good performance for a wear-resistant rotary drag bit.

Rotary Drills - Impart two basic actions through the bit into the rock: axial thrust and torque. Rotary drills have higher torque than either percussive or rotary-percussive drills and require high sustained thrust. Rotary drills are distinguished on the basis of the drill type. These are roller bits, diamond bits, and drag bits.

Roller Bits - Penetrate the rock mainly by crushing and chipping. They have conical cutters, usually made up of sintered tungsten carbide, that revolve around axles attached to the bit body. When the load is applied, the cutters roll on the bottom of the hole as the drill stem is rotated. They are available in sizes from three to 26 inches.

Diamond Bits - Include those which cut full holes and those which take a core. When drilling with diamond bits, the hole is advanced by abrasive scratching and plowing action. The bit is cylindrical in shape with diamonds set in the contact area. Diamond bits require greater rotation, but less pressure. They are not used much in blasting because they are quite expensive.

Drag Bits - Designed with two or more blades. These blades are faced with sintered tungsten carbide inserts. They are usually used in soft rocks such as clay-shales.

Power Augers - Used in soft formations to speed up the removal of cuttings. The bit consists of a flat blade that continues up the shaft as a spiral. Cuttings move away from the bottom of the hole along this spiral. They are used in very soft rocks.

Percussive Drills - Penetrate rock by the action of an impulsive blow through a chisel or wedge-shaped bit. Repeated application of a large force of short duration crushes or fractures rock when the blow energy is strong enough. Torque, rotational speed, and thrust requirements are lower for these systems than for rotary or rotary-percussive systems. Penetration rates in percussive drilling are proportional to the rate at which energy is supplied by a reciprocating piston.

Percussive Machines - Include churn drills, surface hammer drills, down-the-hole hammer drills, and vibratory drills.

Hammer Drills - Capable of drilling holes one and one-half to five inches in diameter. Hammer drills are used extensively for blasthole drilling.

Jackhammers - Hand-held air or gasoline driven tools weighing from 37 to 57 pounds. Air driven models require 60 to 80 cubic feet of air per minute. Hole sizes range from one and one-half to two inches; depth runs from two to eight feet.

Wagon Drills - One of the more useful tools in rock excavation (usually mounted on rubber-tired wagons). Today, however, they are being replaced by crawler drills. These are heavier units capable of drilling holes between two and one-half to five inches, at any angle in all types of rock. They require 50 percent more air than wagon drills—450 CFM. Hole depths of 40 feet are routine and have reached 100 feet in some cases. Crawler drills produce blastholes two to three times more per shift than wagon drills.

Rotary-percussive Drills - Impart three actions through the drill bit. These are rotary action, axial thrust (of lower magnitude than rotary drilling, but higher than in percussive drilling), and impact. The mechanism of rock failure may be considered as a combination of the rotary and percussive.

THE IMPORTANCE OF DRILLING AND THE DRILLER

The best planning, figuring, calculations, and explosives are worthless if the area to be shot is not drilled properly and responsibly. Basically, if the drilling goes bad and is off pattern, the entire blasting program will fail. If the driller is informed to remain on a specific pattern, he must stay on the pattern and not alter it unless he consults with the blaster-in-charge.

The driller must also keep the blaster informed of any changes in the rock that he is drilling or any mistakes he makes so that the blaster may make adjustments to the shot. The driller informs the blaster about cracks and shifts in the rocks, changes in the strata and sand, or mud seams in the rock, so that explosives can be loaded in the hole with these factors taken into consideration. The driller must also inform the blaster of any "short holes," any holes that are not the expected or planned depth. In other words, the driller serves as the eyes of the blaster. Consequently, the drill and driller can make or break a blasting operation.

BENCH BLASTING

The most common method of production blasting in quarrying, strip mining, and construction excavation is BENCH BLASTING. This method involves inclined, vertical, or horizontal blastholes drilled in single or multiple row patterns to depths ranging from a few to 100 feet or more, depending on the desired bench height. Where the excavation is shallow (less than 20 feet), one level may suffice. In deep excavations, a series of low benches, offset from level to level, are recommended for operational convenience. Bench height is often two to five times the burden, and the ratio of burden to spacing is often l:1.25 to 1:2.

SECONDARY BLASTING

Bench blasting ideally reduces all rock to a desired rubble size range. This is basic in order to facilitate handling of rubble or muck to meet limitations imposed by equipment, such as bucket size, or to produce a usable material.

Actually, even a satisfactory blast may leave a few oversized blocks that must be broken by blasting with a light charge placed in small drill holes in the boulder, a technique known as BLOCKHOLING. A quick method for smaller boulders, MUDCAPPING, involves blasting with a part of a stick of powder or a small, bagged binary charge placed against the boulder and covered with mud or a bag of sand. Plastic bags filled with water can also be used. Mudcapping and blockholing may produce objectionable air blasts. Breakage with a drop ball may be preferred, whenever that equipment is adequate and available.

Boulder outcroppings in fields under preparation for farming or on road right-of-ways may also require blasting. There are four methods commonly used in blasting rock boulders and outcroppings. Two have been discussed: mudcapping and blockholing. Another method, SNAKEHOLING, includes the placement of explosives under the rock. SEAM BLASTING is used when the blaster is lucky enough to find a crack or seam, and load the explosive charge into it. The method selected will depend upon a number of factors, including the equipment at hand and the depth of the rock in the earth. Secondary blasting is noisy and generally produces many flying fragments. Accordingly, it is seldom suitable for use in residential areas.

LIFTERS AND SNAKEHOLES

Rough terrain or loose overburden may prohibit drilling the bench from the top. In such cases, LIFTERS (nearly horizontal blasthole charges), may be used instead.

SNAKEHOLES are similar to lifters except that they are always located at the toe of the slope. They should be inclined slightly downward. Snakeholes may also be supplemented above with rows of lifters inclined 20 to 30 degrees upward from horizontal. The pattern is commonly fired in sequence, starting at the top. High quarry faces (75 feet and more) have been successfully blasted using a combination of snakeholes and vertical holes. Lifters and snakeholes are not commonly employed in structural excavation. Their use generally requires that previously blasted rock is excavated before drilling can commence for the following rounds. Snakeholes may produce excessive flyrock, and if they are drilled on an incline to below the final gradeline tolerance, the final rock surface is damaged.

Excavations are also opened by plow or deep "V" cuts where an initial cut is then enlarged in one or several bench levels. The depth of each lift or bench is usually about 10 to 30 feet. Shallower depths prove considerably more efficient. With large or inclined holes, the benches may be 50 feet or more in height, but this should not be considered in structural excavation. Bench heights in cuts through hilly areas change continuously and burden must be modified accordingly.

CHARGE DISTRIBUTION

Rounds in bench blasting should contain an optimum distribution and weight of explosives. The bottom few feet of the hole is usually loaded heavily with a dense, higher velocity explosive in order to pull the toe. Bottom priming helps to carry the toe. In dry holes, where a waterproof explosive is not necessary, free running blasting agents can be used for the entire charge column, if primed heavily at the bottom with a dense, high-velocity explosive.

TRENCHING

Trenching cuts through rock may be a necessary for culverts, pipelines, sewer lines, and other underground utilities. Trenching is inherently difficult because there normally is no relief to the blastholes. Relief must be *created* by the detonation of the first hole or holes, and maintained by the sequential detonation of following holes. Blasting may only loosen material for subsequent removal mechanically or may cast much of the material out beside the trench.

An initial blast of one or two holes creates a crater toward which succeeding delayed charges move the material. A single row of holes is normally used for narrow trenches; two staggered rows are recommended for trenches up to five feet wide; and trenches greater than five feet wide usually require additional rows of holes. Shallow trenches are commonly subdrilled one to one and a half feet, while deeper trenches should be subdrilled 0.3 times the burden. Deep trenches should be blasted in lifts of four to five feet.

The drill patterns used in trenching range from the simple single row of holes to more complex triple-row "Flat-V" or "Five-Spot" patterns. These generally involve delays in various patterns related to rock continuity and trench width, depth, and shape. The simplest hole pattern, a single row of holes, is also the most difficult to make effective unless the trench is very shallow and the holes are closely spaced. Since the initial relief on trench blasts is essentially vertical, each hole load must fragment the rock around it and attempt to move that rock upward out of the trench. This is extremely difficult to do with single-row patterns; either most of the rock, though loosened, remains in the trench or, in the attempt to move it out, the powder load is made so heavy that uncontrolled flyrock becomes a serious problem. Delaying single-row patterns is not a feasible option in many instances, since the hole spacing required for acceptable fragmentation is so close that cutoff risk is high (if the spacing is increased to prevent cutoffs, the blast result is too often individual unconnected craters or even shotgunning of some holes).

Double-row patterns allow for creation of a better relief zone within the trench and the safe use of delays, and are regularly used where trench bottom width ranges from three to about eight feet. Depending on the configuration of the rock at the point of initiation, the holes may be drilled opposite each other in the rows, and delayed by each of the two holes. This approach has the disadvantage of casting all rock down the line of the trench, from which it must be mechanically excavated.

Another option is to delay by row, sometimes called "side casting," which if properly timed, allows for casting some to most of the rock out of the trench, but often increases the cutoff risk because of the relatively close distance between rows. The most common and generally effective approach is to offset the holes in each row and employ an echelon delay sequence, often with an opposite hole at the initiation point to provide a larger initial relief zone. This method has the advantage of allowing the safe use of delays in a pattern which casts much or most of the rock to one side of the trench. Another distinct advantage of double-row patterns is that they allow angling of the boreholes, greatly enhancing the ability of the fragmented rock to move up and out of the trench.

Where trench bottom width increases beyond six or seven feet, the use of triple-row patterns becomes more common. This configuration extends the advantages of double-row patterns (use of delays, trench-clearing delay patterns, angled trench-side holes) to the wider trenches. One of two delay patterns is typically chosen: the echelon pattern or, in very wide trenches in competent rock, a Flat-V pattern. The Flat-V pattern may sometimes produce cleaner trench walls, but has the disadvantage of casting all rock down the line of the trench as in the double-row pattern.

Effective and safe trench blasting, given the constraints of vertical relief and tight hole patterns, shares much with shaft and tunnel blasting. All include the difficulty of and the necessity for accurately judging rock type and competence, and controlling drill alignment. Trench blasting should not be undertaken by the novice blaster. Working with an experienced trench blaster is a prerequisite to safe and effective trenching.

NEED FOR CONTROLLED BLASTING

Overbreak and fracturing, or BACKSHATTER, from excavation blasting often necessitates the removal (scaling) of loose material beyond the designed face. In addition, blast damage to the final rock face may cause instability and rockfall hazards. For these reasons, among other, controlled blasting is extremely important in excavation for structures and elsewhere.

Controlled blasting techniques minimize overbreakage and permit steeper slope designs because of increased mechanical stability and resistance to weathering. The techniques also reduce deeper fracturing and weakening of the finished excavation. These methods can also be used to cut an excavation to accurate lines and around vertical and horizontal corners. Improved appearance of rock slopes may also result. Four controlled blasting techniques in use today are: pre-splitting, smooth blasting, cushion blasting, and line drilling.

Pre-Splitting

Sometimes called "pre-shearing," this technique is based on the fact that the detonation shock wave is

stopped at and reflected from any "free face," including a crack or seam. In pre-splitting, a crack (free face) is created at the excavation line *prior to* the detonation of the main fragmentation load. A row of holes is drilled along the excavation line, at a spacing of four to 10 times the hole diameter (depending on rock type and competence), and with a burden distance to the adjacent row of production-blast holes of 0.5 to 0.7 times the main blast burden. Pre-split holes must be large enough to allow decoupling of the explosive load at 2.5:1 to 3:1 (i.e., a one-inch diameter cartridge in a three-inch hole), which reduces the risk of excessive hole crushing or backshatter. The initial load in pre-split holes is usually 1/4 pound per foot, the load being subsequently adjusted as results dictate. Some blasters never stem the pre-split holes, but the normal approach is to block the hole above the highest explosive charge and stem the hole above this block; using a section of plastic hole liner to contain the stemming is an efficient way to do this.

The pre-split row is fired *before* the main production blast, either as a separate blast or by using delays to achieve 100 to 200 milliseconds between pre-split row detonation and main blast detonation. In theory, the fragmentation generated by the main blast proceeds and is halted at the pre-split crack, leaving a sound face. It must be remembered that the pre-split blast generates little or no fragmentation other than the between-holes crack, so load, properly distributed, to affect both the normal row burden and the behind-row burden. This fragmented burden between the pre-split and adjacent main blast rows will not be cast away from the excavation line, but will collapse to its base.

Since the mechanism by which the crack is generated between pre-split holes is not fully understood (it may be either compression-wave-generated radial cracking, or gas-pressure-generated tensile rock failure, or some combination of both), there are a variety of explosives considered suitable for pre-split loads. The pre-splitting theory accepted initially was radial cracking, which resulted in a dependence on very high-velocity products. However, successful pre-splitting has been achieved with low-velocity emulsions, and even Pyrodex. Today's market offers a range of pre-split products from high-velocity water gels packaged in one-inch by 50-foot rolls to lower-velocity emulsions and dynamites packaged in cartridges 16 to 24 inches long. Some pre-splitting has been successfully accomplished using 200 to 400 gr/ft detonating cord as the load in one and one-half to two-inch diameter holes.

The effectiveness of the pre-split technique is extremely dependent on maintaining excellent drill alignment. For that reason, the maximum depth for pre-split holes should be 40 feet, and the maximum alignment deviation allowed in any direction is six inches in 50 feet (i.e., one percent).

Developing an effective pre-split design, which can vary by rock type and competence even within a single blast, requires adjusting the initial design as blast results indicate. It will be found that the factors which most often cause the poor results are: 1) poor hole alignment, 2) holes too far apart, 3) hole load in pounds per foot either too high or too low, and 4) decoupling either too high or too low.

Smooth Blasting

The principle in smooth blasting is to control the load distribution and the shock wave energy release in the excavation-line holes to produce between-holes shearing, while preventing back-shatter or excessive hole crushing. The holes along the excavation line are given a spacing not greater than 0.7 times the row burden, and the per-hole load is adjusted downward accordingly. The load is decoupled from the hole, usually at around 2:1 (i.e., a one-inch cartridge in a two-inch hole), and the hole is blocked and stemmed above the highest charge as in pre-splitting.

In smooth blasting, normal blast sequence is followed, with the excavation-line row the last to fire. There is normally no delay between holes in the excavation-line row, since that would disrupt between-holes shearing. This technique allows for displacement as well as fragmentation of the burden on the excavation-line row. As with pre-splitting, hole alignment is critical, and poor alignment is the most common cause of poor results. Insufficient decoupling will result in excessive backshatter, which means the additional drilling done to set up the smooth blast will have been wasted.

Cushion Blasting

This technique is the same as smooth blasting, except that the annular space between the cartridge and the hole wall in the decoupled holes is filled with loose, crushed stone. The loose stone partially absorbs, or cushions, the energy of the detonation shock wave. This technique is not widely used due to its requirement for a volume of small, crushed aggregate on the job site (i.e., cost).

Line Drilling and Close Drilling

Line drilling consists of placing a row of unloaded drill holes along the excavation line, spaced on centers no more than two times the hole diameter. These form a surface of weakness to which the primary blast can break. They also reflect some of the shock waves. Increased use of pre-splitting for economical reasons has reduced line drilling to a supplementary role. Line drilling may be required prior to pre-splitting for at least 10 feet in both directions from a 90-degree corner. In this procedure, the depth of pre-split holes must not exceed that of the line-drill holes.

In line drilling, the primary blasting is conducted to within two or three rows of the line-drilled row to decrease the burden. The row of primary blastholes nearest the line-drilled row should have 75 percent of the usual hole spacings, and should be 50 to 70 percent closer to the line-drilled row than to the last primary row. The powder factor may also be reduced.

Because of the tedious drilling necessary, line drilling is more useful in easily drilled homogeneous rock. Despite high costs, line drilling has application where even pre-splitting may cause excessive wall damage (such as 90-degree corners in excavations, or steps in bedrock), and it may be required where other structures are adjacent to an excavation.

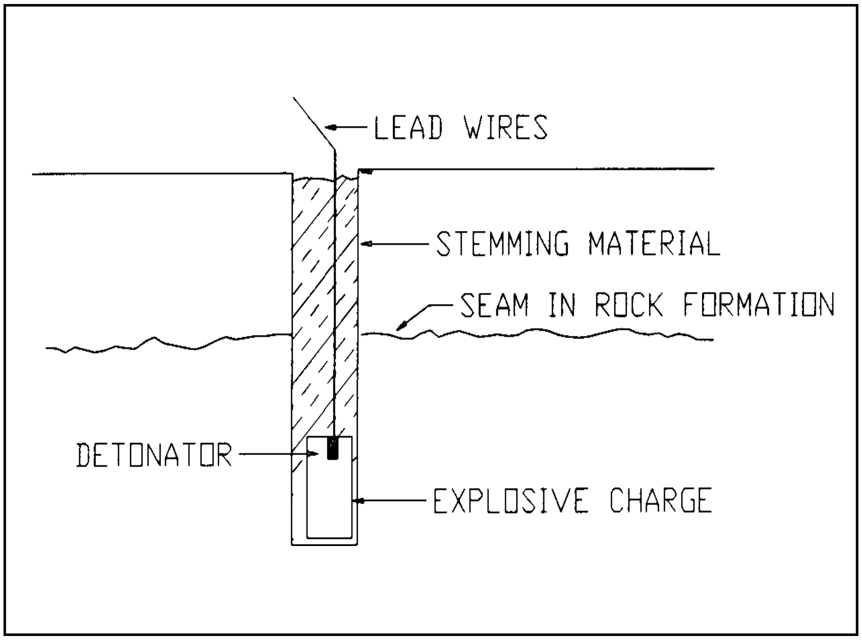
Close drilling may be specified for finished surfaces not requiring line drilling. Close drilling consists of holes spaced farther apart than line-drilled holes, but closer than pre-split holes. The holes may be loaded or unloaded as necessary for proper blast performance.

SHOCK ENERGY/HEAVE ENERGY

Two kinds of energy are created at the detonation of an explosive:

A. Shock Energy - The velocity-shock breaks or cracks rock, but does not move the rock. The harder the rock, the better this energy works. Change in formation density, cracks, mud seams, etc., will cause this energy to return to the area of origination.

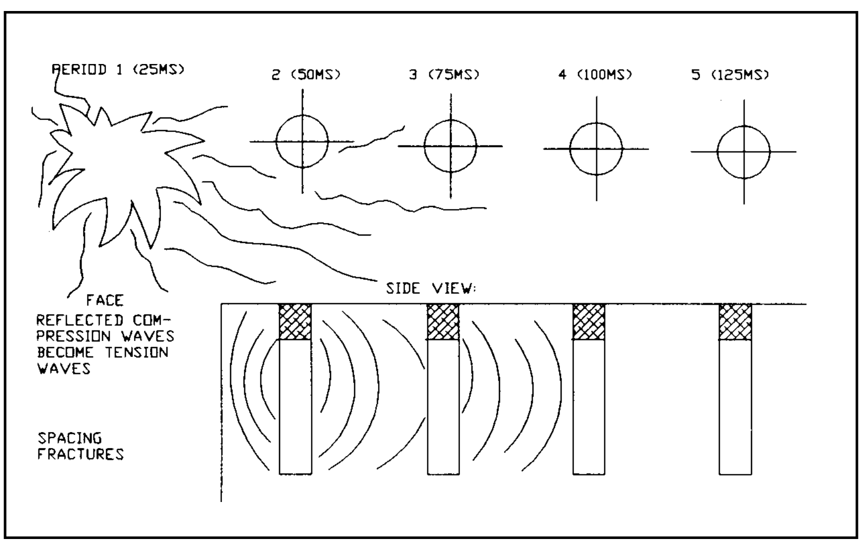
B. Heave Energy - The energy created by the expansion of the gases formed when an explosion occurs. This energy, trapped in a borehole, performs useful breaking of rock and is the energy that displaces the rock when the explosion occurs.



(Figure 9-1) It is possible to fracture the rock in the bottom portion of a borehole without disturbing the upper portion of the borehole.

Dead Pressing

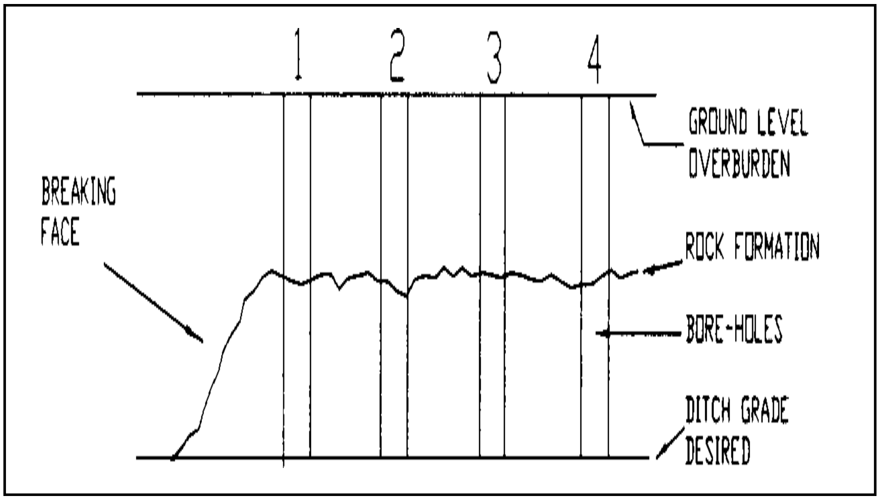
Dead pressing is the phenomena that affects the critical diameter of an explosive causing misfires. Explosives most affected by this phenomena are slurries and water gels.



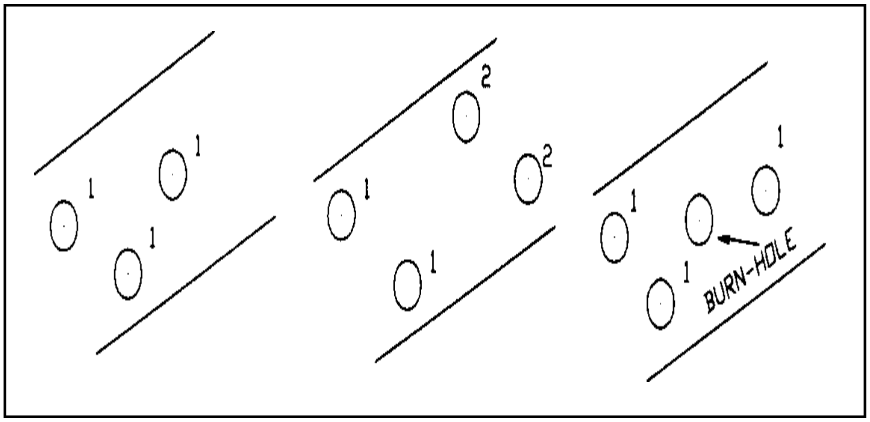
(Figure 9-2) Dead pressing.

The Breaking Face

In order to conduct good ditch line shooting, it is necessary to have a face to break to. In rare instances in excavating, the rock ledge, when encountered, is abrupt enough to be considered the "breaking face." In most cases, it will be necessary to create a breaking face.

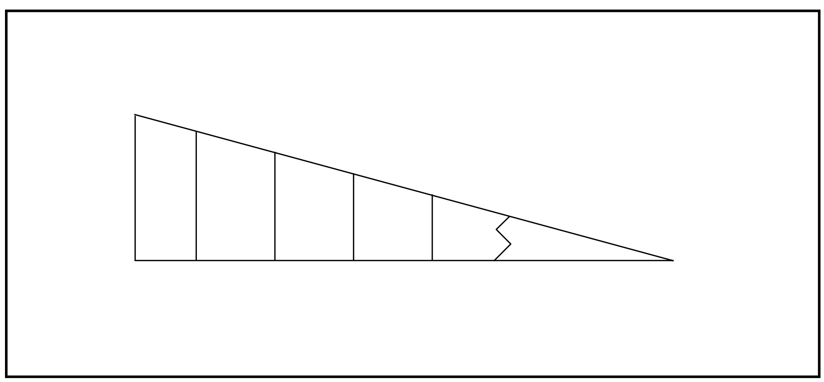


(Fig 9-3) The breaking face.



(Figure 9-4) Suggested patterns for creating the breaking face.

If a rock ledge is as much as six feet to the bottom of the borehole, double priming should be considered. Once a breaking face is created, it must be maintained. If a hole is lost in the ditch line, the breaking face may be lost. In almost every case, loss of the breaking face will result in secondary blasting.



(Figure 9-5) Breaking face on incline.

In order to maintain the breaking face on inclines, it is necessary to create the breaking face at the lowest point in the ditch line.

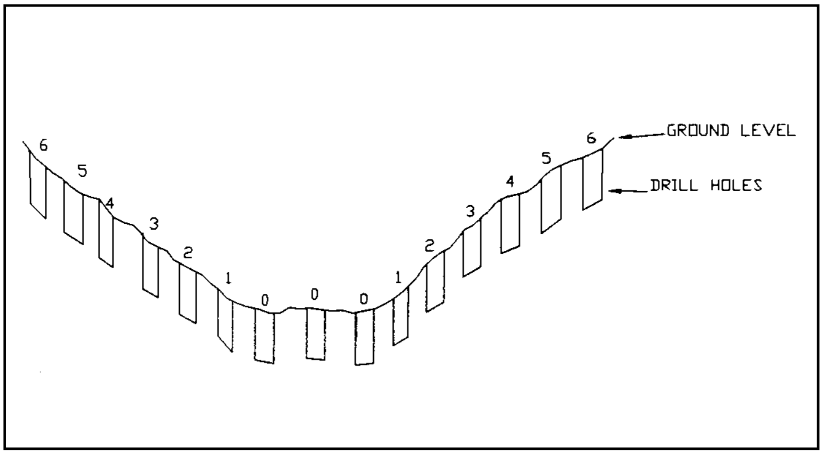
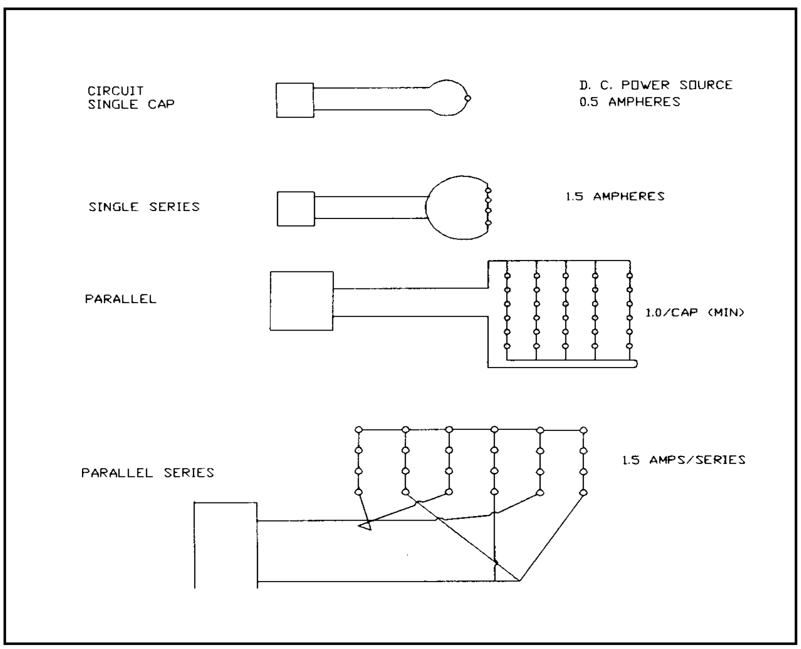
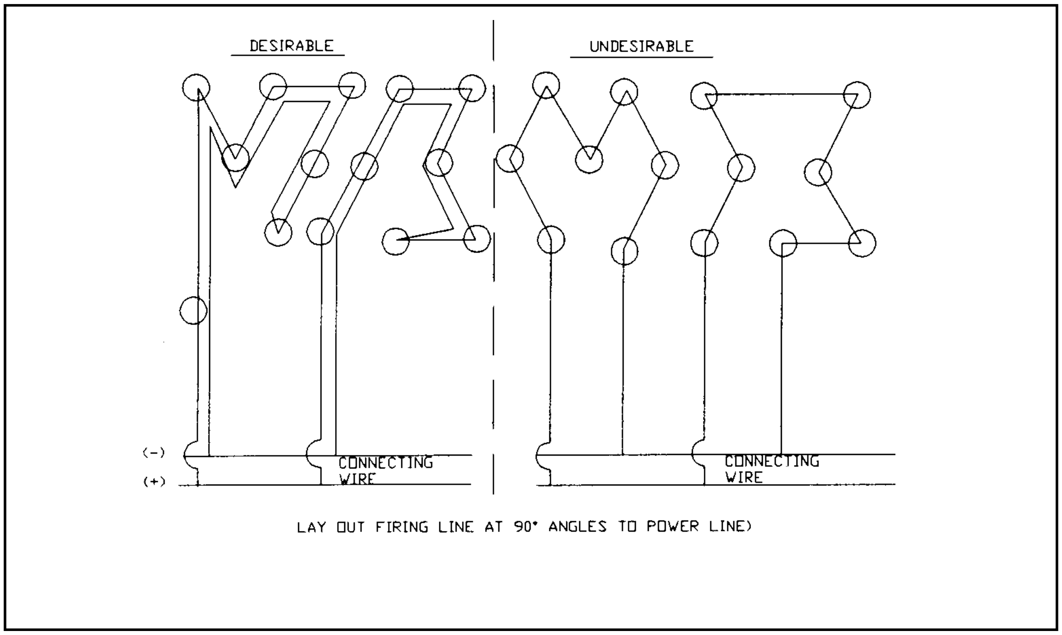


Figure 9-6) Numbers indicate electric blasting cap delay number.



(Figure 9-7) Minimum firing currents.



(Figure 9-8) Preferred circuit layout under power lines if inductive coupling is a possibility.

USE OF ELECTRIC BLASTING CAPS IN THE UTILITY AND LIGHT CONSTRUCTION INDUSTRY

Electric blasting caps are more reliable and versatile than any other detonating system on the market today.

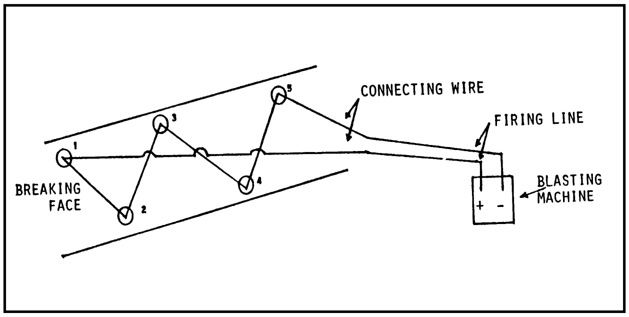
Instant E.B.Caps -These caps should be used when delay caps are not needed. They are less expensive than delay caps.

Delay E.B. Caps - Delay caps should be used when:

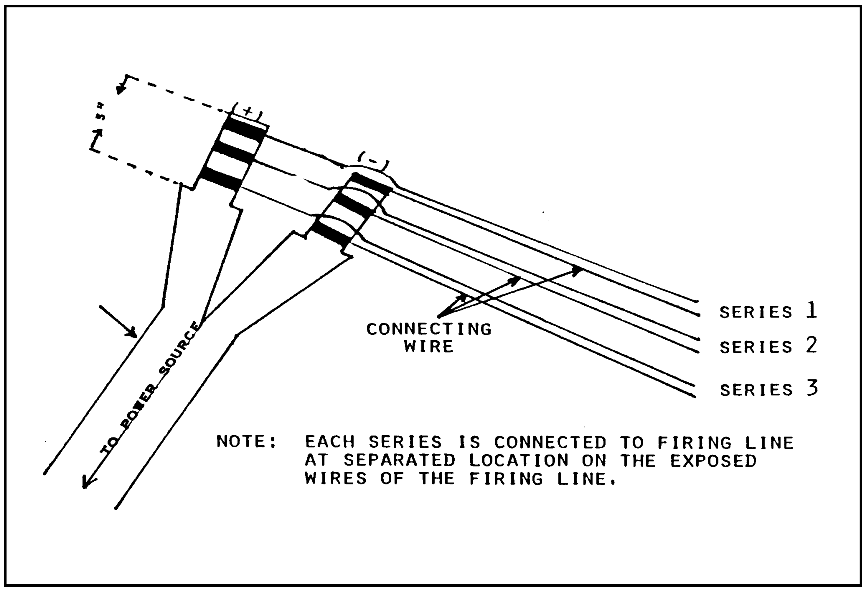
A. Control of shock energy in the formation is critical.

B. Better rock breakage can be obtained by creating an area in the ditch line or pit for the fractured rock to move to.

Note: It is estimated that it takes 17 milliseconds for the rock to start moving after the explosion occurs in the borehole. For best fragmentation and controlled movement of blasted material, the delay between boreholes should be 18 milliseconds or greater.

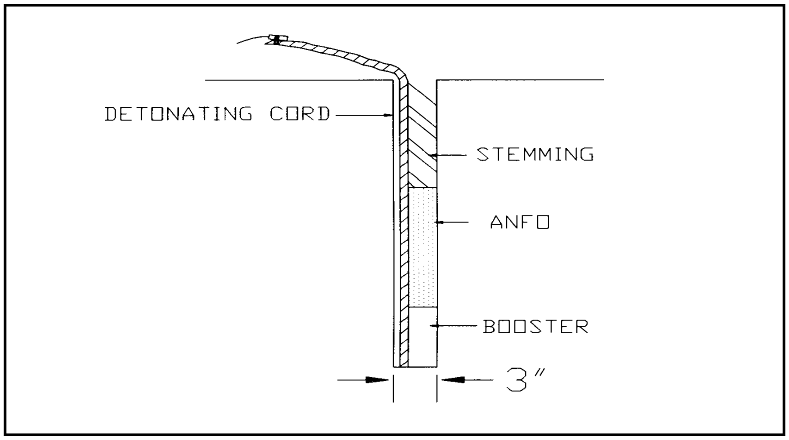


(Figure 9-9) Electric blasting cap series.



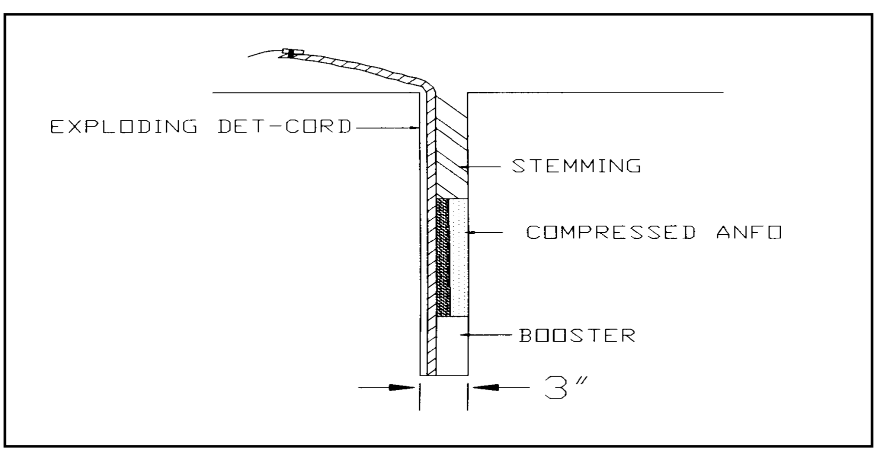
(Figure 9-10) The above diagram shows proper method of attaching connecting wires to a firing line, when two or more series are used.

E.B. Cap Series - Any number of electric caps connected together in a continuous circuit is considered a series. Any time two or more caps are used, they should be wired in series.



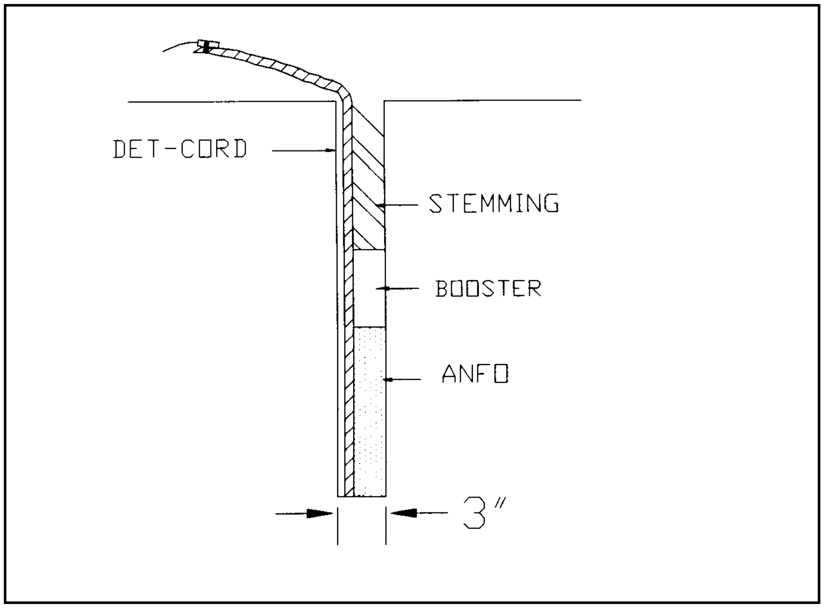
(Figure 9-11) The most common method of loading boreholes with ANFO using detonating cord as the detonator for the booster in 3 1/2" or smaller boreholes.

In the use of delay E.B. Caps with slurries, water gels, and two-component explosives, the use of full or half-second delays is not recommended in trench shooting. Better results and less dead pressing occur when the millisecond delays are used.



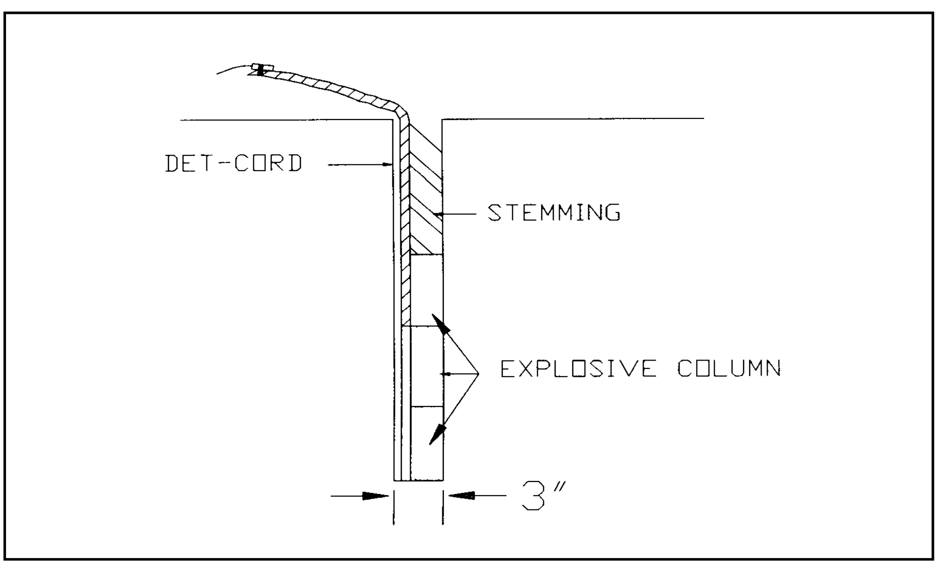
(Fig 9-12) Dead press effect.

"Dead press effect" or burning of the ANFO column when the detonating cord explodes, can cause a loss of as much as three quarters of the total energy in the column.



(Figure 9-13) Proper use of detonating cord and ANFO in 3 1/2" or smaller diameter boreholes.

“Dead press effect,” or burning of the ANFO column when the detonating cord explodes, can cause a loss of as much as three-quarters of the total energy in the column.



(Figure 9-14) Proper use of detonating cord with water gels or two-component explosives.

USE OF DETONATING CORD IN CONJUNCTION WITH E.B. CAPS IN EXCAVATING OF PITS, LAGOONS, LIFT STATIONS, SWIMMING POOLS, & BASEMENTS

Note: Each number indicates increasing period of delay. Delays used are 25 milliseconds increments.

Examples:
#1 = 25 milliseconds
#2 = 50 milliseconds
#3 = 75 milliseconds

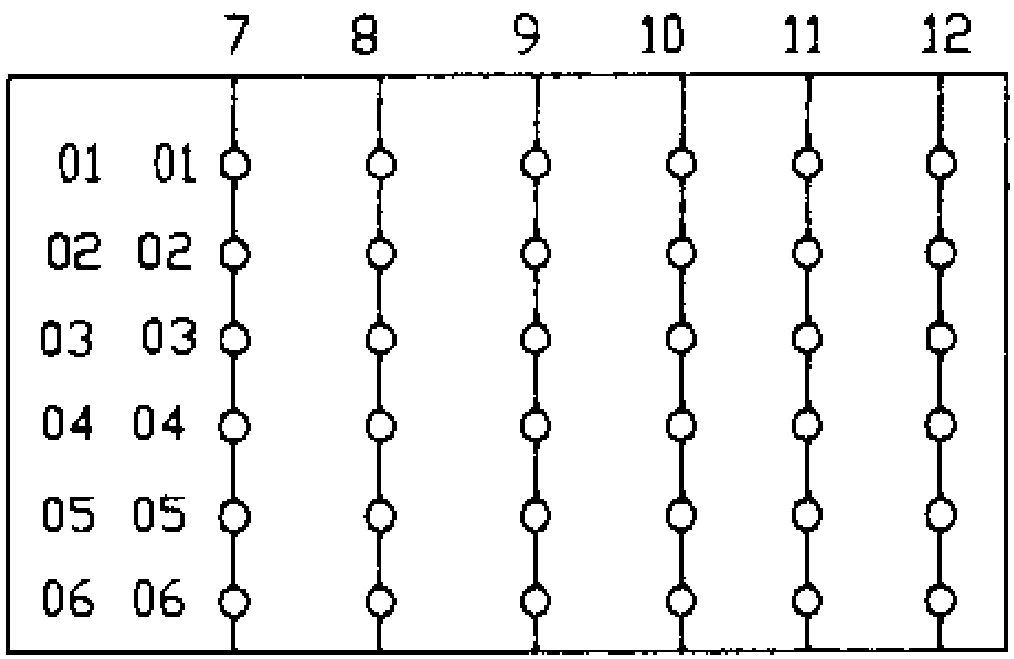


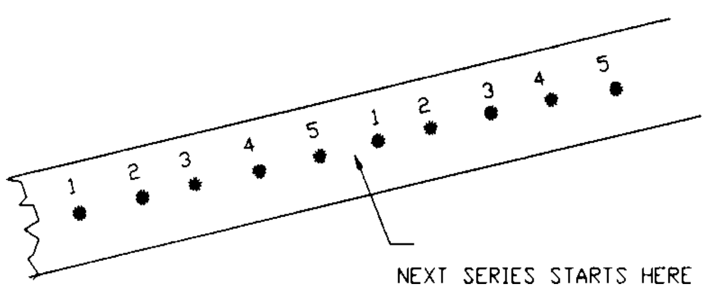
Figure 9-15) Proper use of detonating cord and ANFO in 3 1/2" or smaller diameter boreholes.

Note: The first two rows of holes are delayed to shoot as a ditch line would be shot. The rows of holes after that are delayed to shoot toward the breaking face created by the first two rows.

USE OF DETONATING CORD IN SAVING THE BREAKING FACE IN DITCH-LINE SHOOTING

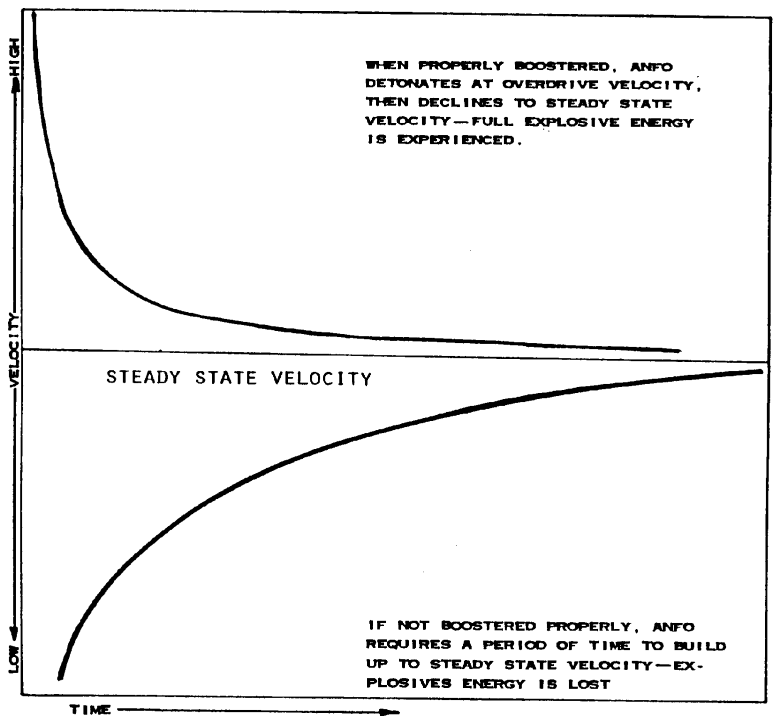
Note: Each number indicates increasing period of delay. Delays are in 25 milliseconds increments.

Example:
#1 = 25 milliseconds
#2 = 50 milliseconds
#3 = 75 milliseconds

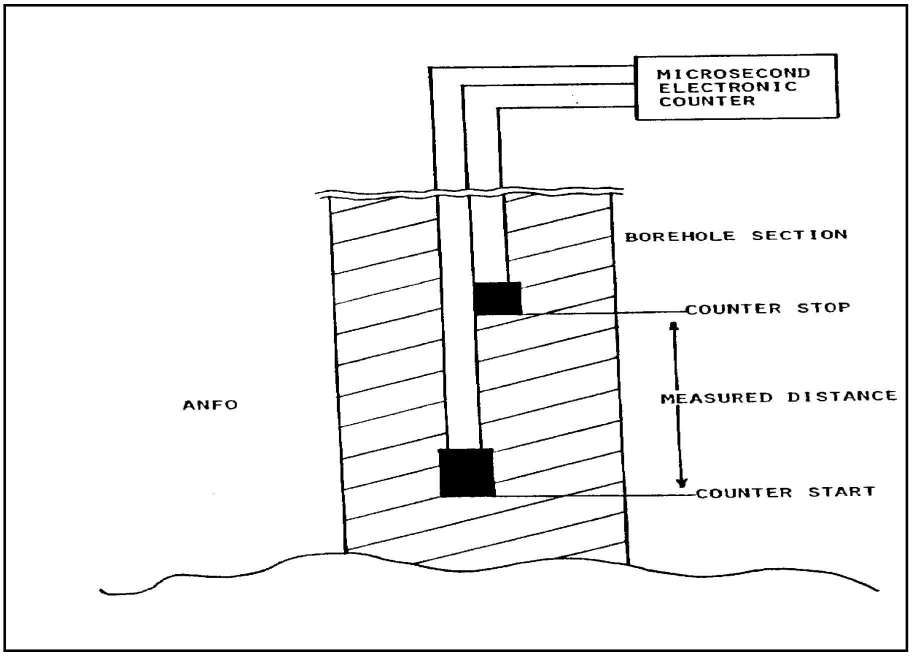


Load the first hole in the next series with the explosive charge desired, using detonating cord as the detonating device for the column. Leave plenty of slack in the cord all the way to the top of the hole. Do not stem at this point. Detonate the first series. The first hole in the next series is already loaded, stem if possible, attach correct delay cap and proceed to load next holes as usual.

THE RELATIONSHIP OF BOOSTERING AMMONIUM NITRATE FUEL OIL MIXTURE TO DETONATION VELOCITY

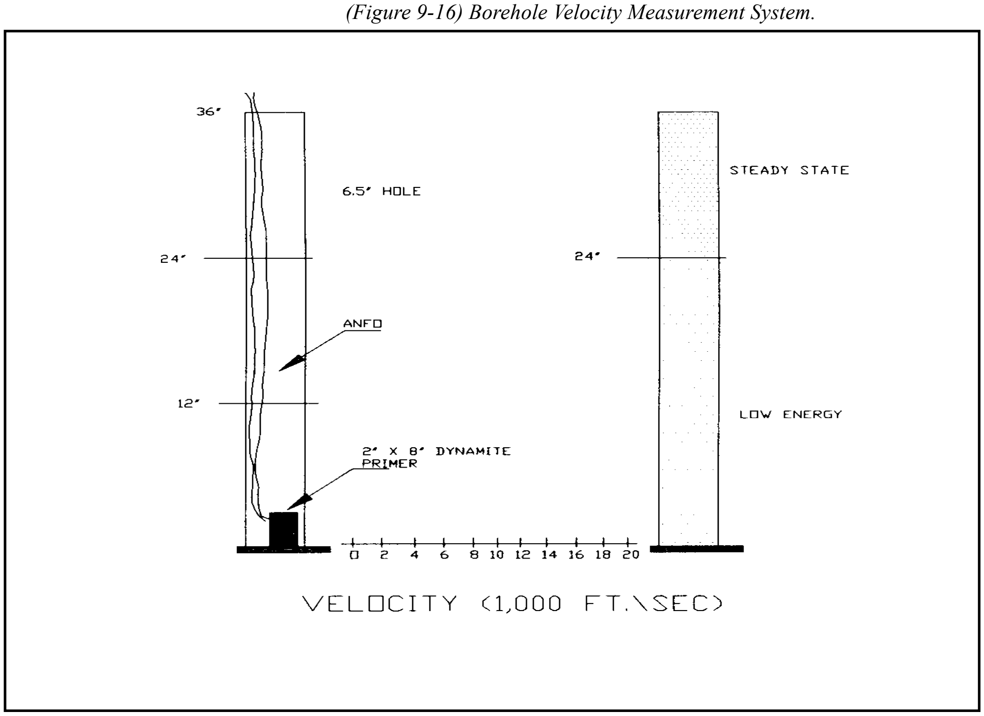


(Figure 9-16) Proper use of detonating cord with water gels or two-component explosives.

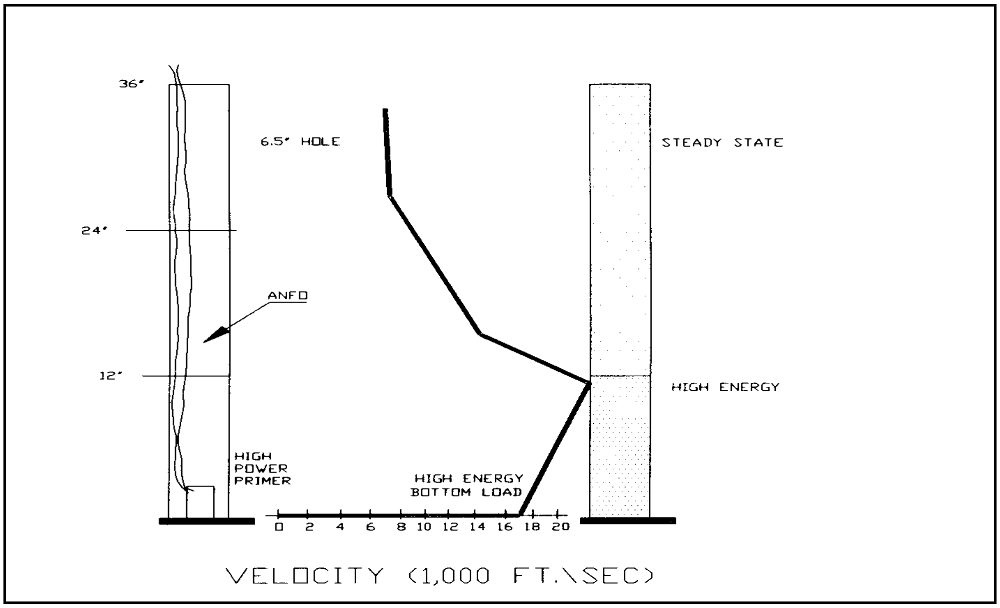


(Figure 9-17) Borehole Velocity Measurement System.

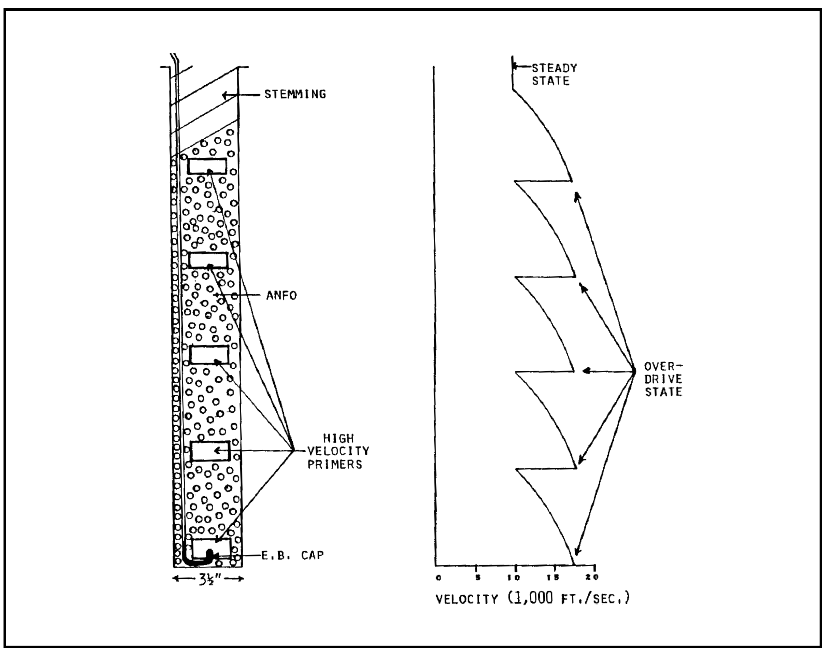
(Figure 9-16) Borehole Velocity Measurement System.



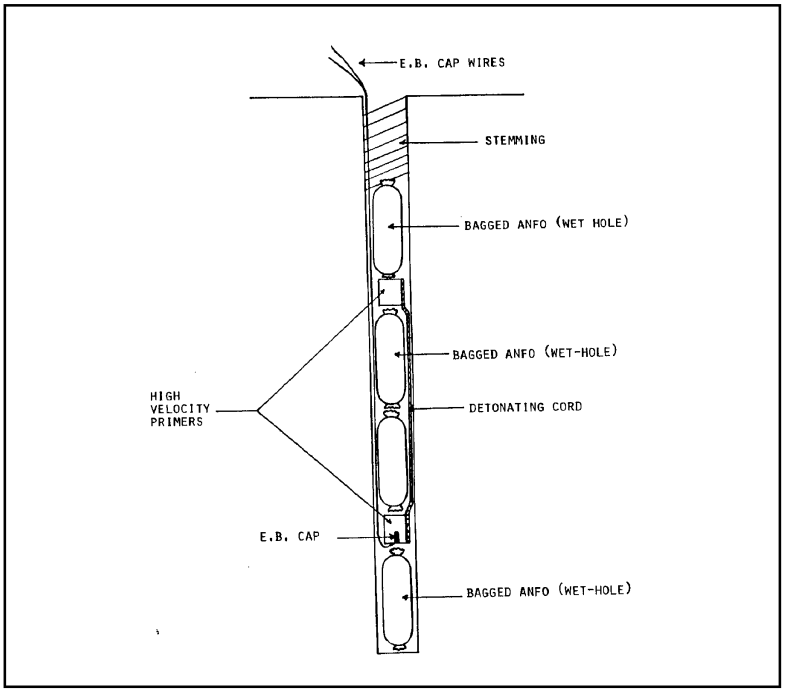
(Figure 9-18) Inefficient priming.



(Figure 9-19) Good priming.



(Figure 9-20) Overdrive effect from good priming in 3 1/2" dry hole.



(Figure 9-21) Good loading procedure for bagged ANFO (wet hole) 4 1/2" diameter or greater.

Due to the time required for an explosive to become effective and build up pressures in the borehole, it is necessary to subdrill past the desired grade. The distance to consider for overdrilling is dependent on the rock formation and the velocity of the explosive to be used.

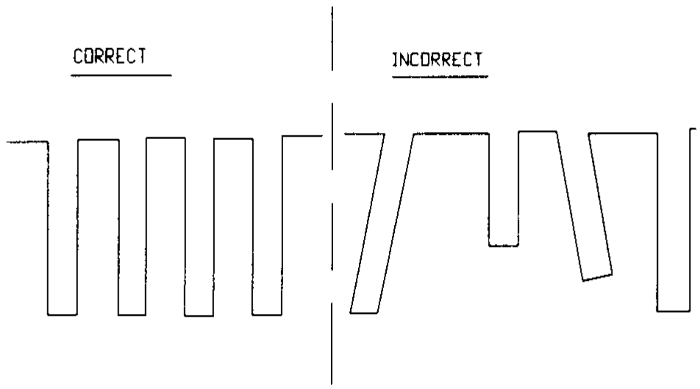
For best production results, the driller should be three to four hundred feet ahead of the blaster at all times. It is up to the blaster to keep his "breaking face" open by not losing any holes. The diagram below shows the correct and incorrect drilling practices:

USE OF AMMONIUM NITRATE FUEL OIL IN THE UTILITY AND LIGHT CONSTRUCTION INDUSTRY

These industries normally use drilling equipment that does not lend itself to the use of ANFO (3 1/2" diameter holes or smaller). ANFO used in these diameters will not achieve velocities high enough to do an effective job of fracturing the rock formation. It is possible to overdrive the ANFO as explained before, but this can be very expensive.

If the diameter of the borehole exceeds the diameter of the explosive by more than one-half inch, borehole coupling can be achieved very effectively by filling in the air space around the ANFO with stemming.

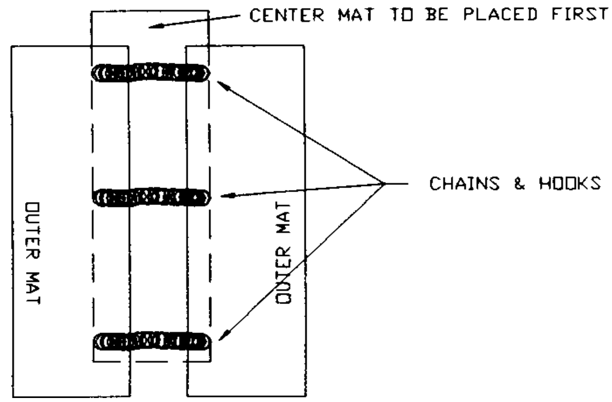
CAUTION: ANFO has more gas energy (heave) than any other explosive. This very often results in more flyrock and less control of desired dimensions in tight shooting conditions.



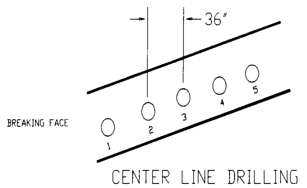
The driller's responsibility is to:
A. Maintain exact distances between holes.
B. Keep hole depth uniform.
C. Keep holes vertical to one another.
D. Notify blaster of changes in drilling, overburden, rock depth, lost holes, etc.
E. Cover the drilled holes.

USED CONVEYOR BELTING BLASTING MATS

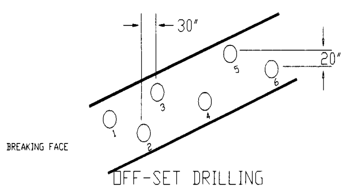
This mat consists of three parts:
1. The center mat is without chains.
2. The two outer mats have short pieces of chain bolted to them.
3. The mat should be placed over the area to be protected in the following manner:



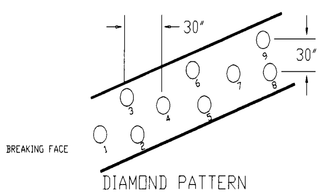
TRENCHING (TRACK DRILL)



24" ditch width, 0"-48" grade depth (drill hole depth = grade + 12")



24"-36" ditch width, 48" - 144" grade depth (drill hole depth = grade + 18")

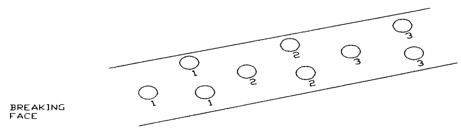


36-48" ditch width, 48"- 144" grade depth (drill hole

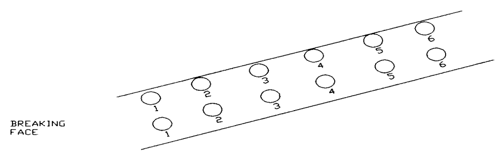
Note: This is an exceptionally good low density rock formation pattern.

Note: Maximum fragmentation of rock is achieved when holes are laid out and fired in a triangle. The converging shock waves from the configuration can often allow the use of less explosives in each hole.

When adjusting all patterns to meet your needs, spread or close drill patterns in six-inch increments until desired results are achieved.



DIAMOND PATTERN (TRIANGLE DELAYED)



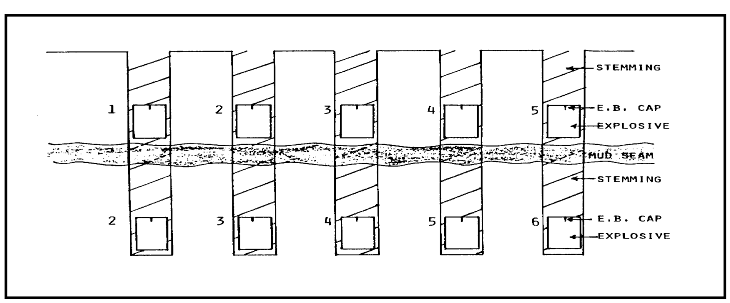
DOUBLE ROW DRILLING

DOUBLE PRIMING

Double priming should be considered when the solid rock in a borehole depth is eight feet or more, or there is a mud or earth seam in a formation of four inches or more.

Allow for a minimum of 10 inches stemming below and above the mud seam before placing the top charge.

The necessity of double priming will depend on the thickness and density of the rock, as well as the continuity of the formation. In many formations, the heave energy will lift and fragment the upper layers of the formation without double priming.

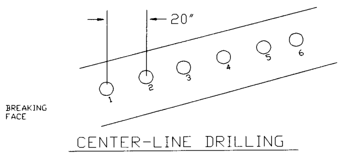


(Figure 9-22) Double priming. Numbers indicate electric blasting cap delay period.

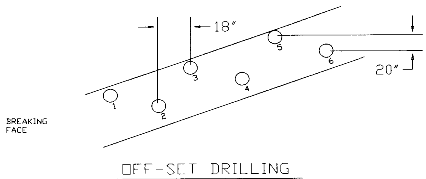
This mat should always be used with a minimum of eight inches of overburden between the top of the rock and the blasting mat.

Note: When connecting the chain of the outer mats across the center mat, do not leave any slack in the chain.

TRENCH SHOOTING (HAND-HELD ROCK DRILL)



12"-18" ditch width (drill hole depth = grade + 12") This type of shooting involves the use of small diameter explosives (1"-1 7/8" diameter).



18"-24" ditch width (drill hole depth = grade + 12")

When using a hand-held rock drill, it is best to drill no deeper than four feet at a time. Manpower efficiency decreases, and drill steel hang-ups increase dramatically past this depth. It is more economical to drill the four feet, shoot, clean out, and drill again if greater depth is needed.

PIT SHOOTING

The breaking face is created at the bottom of the Diagram A by shooting the first two rows as a trench line is shot. The balance of the holes are delayed to move toward the created breaking face one row at a time.

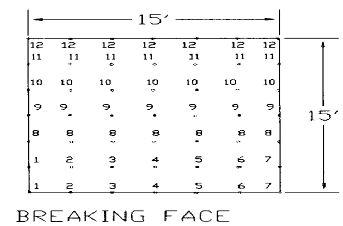


Diagram A

This diagram is for track drill, using a 2 1/2" drill bit, 3-foot spacing between holes, 2" diameter explosive, and 1-12 milliseconds delay periods.

The breaking face in Diagram B is created in the center line, moving toward the bottom of the diagram with the sides folding into center on different delays.

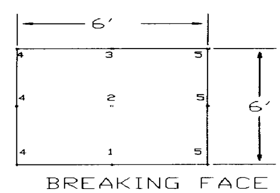


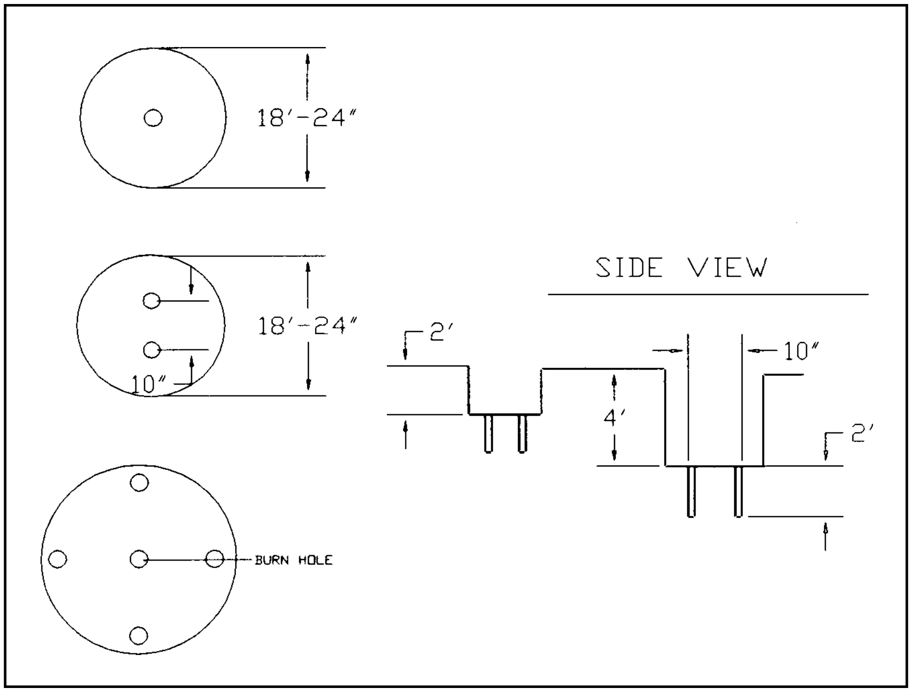
Diagram B

This diagram is for track drill using 2 1/2" drill bit, 3-foot spacing between holes, 2" diameter explosive, and 1-12 milliseconds delay periods.

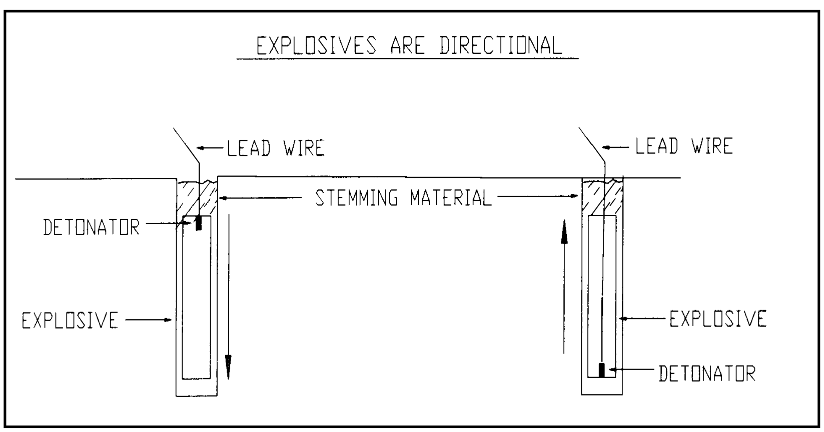
POLE HOLE SHOOTING

Drill a single hole two feet deep where the pole will be set. Use one stick of powder (1 1/4" x 8") with cap inserted to shoot toward the bottom of the hole and clean out. Drill two holes 10 inches apart, two feet deep. Shoot and clean out. Repeat until desired depth is reached. Depending on the density of the rock, you may use any amount from one-half of a stick to a full stick in each hole.

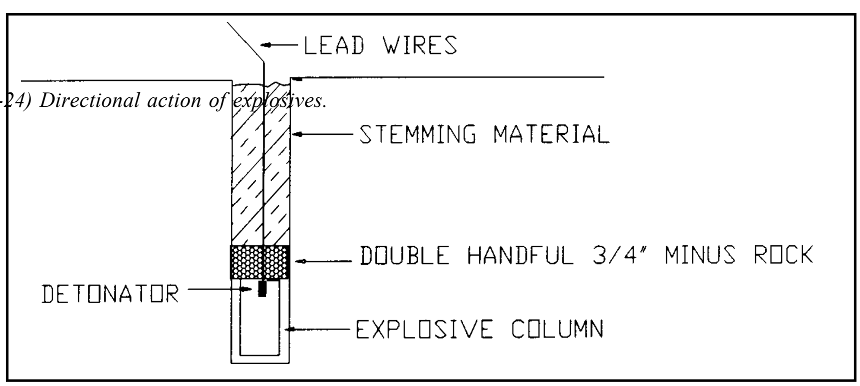
A center hole is drilled, but not loaded, creating a breaking face in the pattern. This pattern is utilized when using hand-held rock drills or track drills where rock formation demands are tough.



(Figure 9-23) Pole hole shooting



(Figure 9-24) Directional action of explosives.



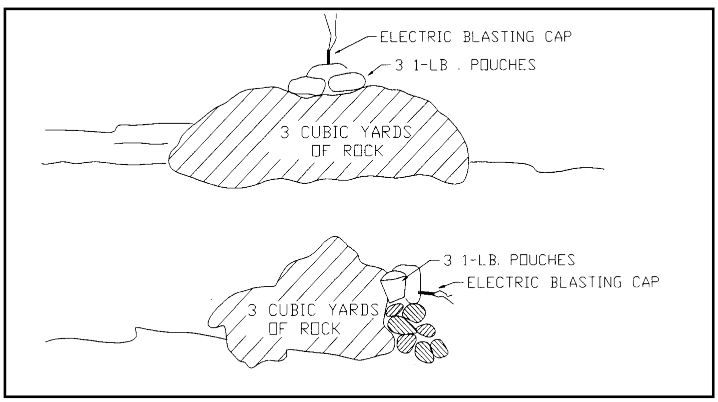
(Figure 9-25) Single hole configuration in pole hole shooting.

BOULDER BREAKING

It is possible to break rock with the shock energy of an explosive without drilling any holes in the rock if the approximate size of the rock is known.

Example: Assume that you need to break a 3-cubic-yard rock (boulder). By using three 1-pound explosive pouches placed as in the following drawing, you can break the rock with the shock energy created by the explosive, in most cases. Very little, if any, flyrock occurs when breaking rock in this manner (shock energy does not throw rock).

Normally, one 1-pound explosive pouch is required per each cubic yard of rock to be blasted. It is possible in many cases to reduce this amount if the blaster wants to take the time to 'dobe' the explosive. This



(Figure 9-26) Boulder breaking. The blasting cap must always be pointed toward the intended direction of the shock energy.

Normally, one 1-pound explosive pouch is required per each cubic yard of rock to be blasted. It is possible in many cases to reduce this amount if the blaster wants to take the time to "dobe" the explosive.

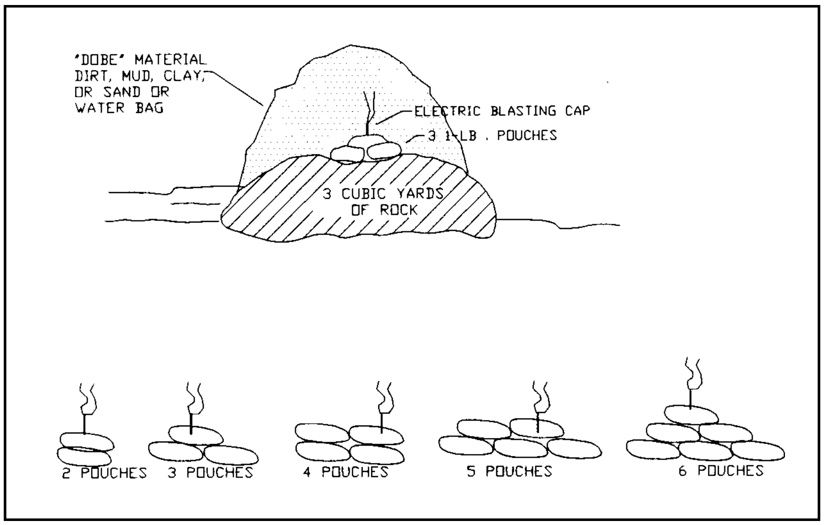
This same principle can be applied to remove small outcroppings of rock in ditch lines, etc., with reasonable success. However, this method is not recommended in solid ledge rock because the shock wave exits but does not return, resulting in very little or no breakage. This method of breaking rock is extremely noisy and should not be done if blasting noise disturbs neighbors in the area where blasting is being considered.

Regardless of where the explosive is placed, if the blasting cap is pointed in the direction of the rock to be blasted, the shock energy in the explosive will be absorbed by the rock. Shock energy will not leave the rock that it enters. If there is a crack in the rock, the shock energy will not exit the crack.

It is important that the explosive maintain intimate contact with the rock. This is the reason the one-pound pouch is in a flexible package, allowing the explosive to conform to blasting surface.

CONVERGING SHOCK WAVE BLASTING PRINCIPLE

This pouch layout can produce extreme pressures within the rock because the converging shock waves meet in the center of the triangle, increasing shock wave intensity many times. This allows larger rocks to be broken with less explosives. All caps should detonate at the same time. The triangle can be different sizes, but should form as close to a perfect triangle as possible. Sometimes it is best to separate the explosive charge over the surface of a rock. Detonation should occur simultaneously in each of the charges, injecting the shock wave throughout the rock at the same time.



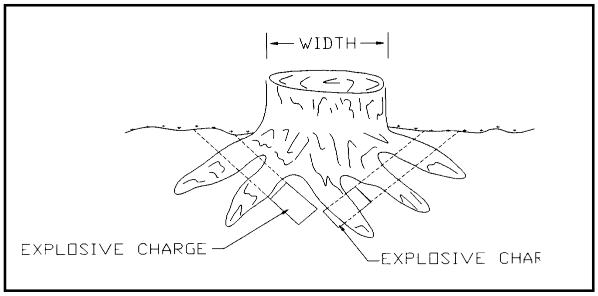
(Figure 9-27) Boulder breaking. The blasting cap must always be pointed toward the intended direction of the shock energy. At bottom are suggested powder stackings for various amounts of 1-pound explosive pouches that allow the greatest penetration of shock energy to rock.

STUMP SHOOTING

The most important thing to remember about shooting stumps is that the explosive must be placed under the stump. The prescribed method is to punch holes under the stump at an angle, toward the center of the stump. The depth of these holes depends on the width of the stump. A 24- to 30-inch-deep hole will suffice for most stumps 5 inches to 18 inches in diameter. A stump 10 inches or more in diameter may require two or more holes. The powder used should be 1/2 pound to every 5 inches of diameter.

Example: A 15-inch-wide stump can usually be lifted out of the ground with 1 1/2 pounds of explosives.

In large diameter stump shooting (three feet or more), it is sometimes necessary to "spring" a hole, or punch it, as deep as possible toward the center of the stump. Place a 1/2 pound charge in the hole and detonate. This usually results in blowing a cavity beneath the stump. Let the hole cool, then clean it out and place the amount of explosive required (using powder factor mentioned in previous paragraph). Fill the cavity back in and detonate.



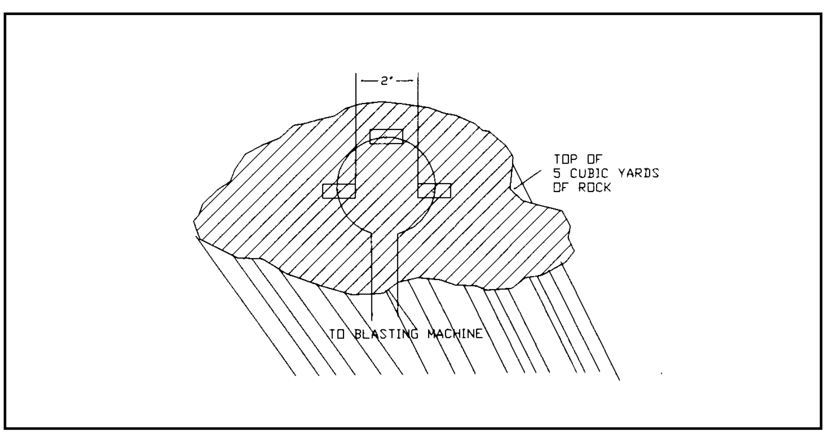
(Figure 9-28) Separation of explosive charges over rock.

When shooting two or more holes, make sure that both holes go off at the *same* time. Electric blasting works best.

Again, it is recommended that the stump is protected with a cover of some kind to prevent pieces of rock or stump from flying into the air. Removal of live tree stumps may require more explosive than a tree stump that has been dead for any length of time. An explosive with good heave energy is best for this type of work. Binary explosives have more heave energy than dynamite.

HAZARD TREE FELLING WITH EXPLOSIVES

Felling hazard trees with explosives is often safer than felling with a power saw because personnel are at a safe distance from the tree when the danger is highest. General blasters and fireline explosives



(Figure 9-29) Large diameter stump shooting with holes punched toward center of stump.

blasters can be certified by National Park Service blaster examiners to conduct hazard tree blasting. All hazard trees must be assessed before they are felled. Extreme care is essential where trees are rotten, weak, on fire, or have significant lean. Always approach a hazard tree away from the lean. When assessing a hazard tree to be felled, determine the following:

1. Is the tree green, dead, hollow, and/or rotten?

A dead, hollow tree will require that explosives be spread across the face to avoid blowing a hole in the center and leaving the tree standing. A live, solid green tree may take slightly more explosives concentrated in one location and shaped in a pyramid to develop an appropriate shock wave. Look for conks, broken tops, basal scars, cat faces, numerous downed limbs, etc., that may indicate rot. Also, look to see if numerous trees are down in an area. This may indicate a pocket of trees with rot.

2. Is the tree burning?

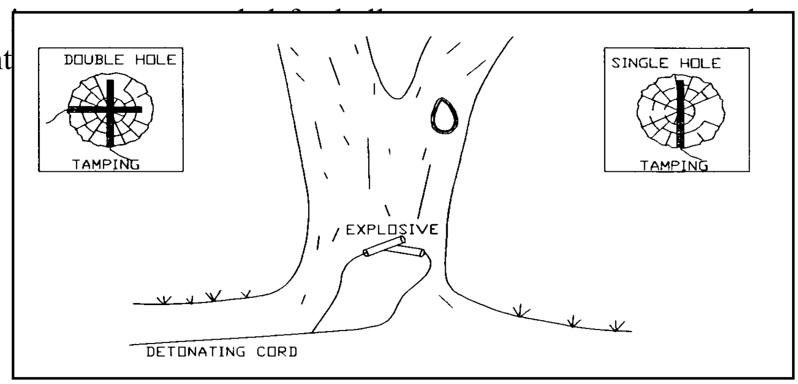
Fire burning in a tree may indicate rot, which results in a weakened tree. If the tree is burning in the top, use only water gel, emulsion, or PETN-based explosives or explosives approved for fireline explosive construction (FLE). If the tree is burning at the base, STOP! Do not use explosives if there is a probability that they will catch fire!

Explosives that are on fire must not be touched! Do not attempt to extinguish explosives that are on fire! Also, if the tree may fall across burn control lines, special precautions may need to be taken.

3. Determine the tree diameter where the explosives will be placed (generally at chest height).

4. Determine whether external or internal blasting methods should be used.

a. The term *internal* indicates that a hole will be drilled in the tree for the explosives charge (Figure 9-28). This method … are so hazardous that the activity might …



(Figure 9-30) Large diameter stump shooting with holes punched toward center of stump.

b. The term *external* indicates that the explosives will be placed on the outside of the tree in one location or by wrapping the tree with linear type fireline explosives. Wrapping is the least preferred method of hazard tree blasting because the direction of the fall is left to chance. Also, not enough explosives will be used when a large tree is single wrapped, which will leave the tree standing and weakened.

Internal Hazard Tree Felling

Internal hazard tree blasting is often preferable to external because less explosive is needed and shock wave and noise are reduced. However, direction of fall is unpredictable and the tree must be disturbed to drill a hole for the explosives.

The formula used for internal hazard tree felling with explosives is:

$W = D /250$ (Metric Equivalent: $W = D /3560$)

W = Weight of the explosives in pounds (Metric Equivalent: kilograms)

D = Diameter of the tree in inches, where the explosives will be placed. (Metric Equivalent: centimeters).

<u>Example</u>: Tree Diameter = 24 inches (Metric Equivalent: 61 centimeters)

2

$W = (24)/250 = 576/250 = 2.3$ pounds

(Metric Equivalent: $(61)/3560 = 1.04$ kg)

When using explosives that are supplied in one-pound sticks, place three sticks (always round up). Using explosives supplied in 0.5 kg sticks, place two sticks. With packaged emulsions or water gels that can be extruded into the borehole, use two to three pounds (1kg).

Using a 1.25-inch linear water gel explosive (fireline), divide 2.3 pounds by 0.6 pounds per foot = 3.83 feet (1.17 meters). Round up and use 4 feet (1.2 meters) of linear FLE explosives.

Once the hazard tree has been loaded with explosives, the procedures for detonation are the same as for fireline explosives. Use exploding bridgewire detonators, the customary 500 feet (152 meters) of shot line for distance requirements, and place appropriate guards. (See special considerations at the end of this section.)

External Hazard Tree Felling

External hazard tree felling is a preferred method because the blaster has a high degree of control over which way the tree will fall. However, air blast will be higher for this method than in the internal method, and it is often difficult to place large amounts of bulk explosives in one location on a tree. An exception is where packaged explosives can be removed or extruded from the container, shaped, and then stuck to the surface of the tree.

The formula used for external hazard tree blasting is:

$W = D /40$ (Metric equivalent: $W = D /569$)

W = Weight of explosives in pounds(Metric equivalent: kilograms)

D = Diameter of the tree in inches, where the explosives will be placed. (Metric Equivalent: centimeters)

<u>Example</u>: Diameter of the tree is 24 inches (Metric equivalent: 62 centimeters)

W = (24)/40 = 576/40 = 14.4 pounds
(Metric equivalent: (61)/569 = 6.54 kg)

When using explosives supplied in 1-pound sticks, place 15 sticks concentrated in one location (always round up). Using explosives supplied in 0.5 kg sticks, place 13 sticks. When using explosives that can be extruded from the package, place 14.4 pounds (6.54 kg).

Using 1.25-inch linear water gel fireline (FLE) explosives at 0.6 pounds per foot, use 14.4/0.6 = 24 feet (7.3 meters) of linear fireline explosives concentrated in one location.

NOTE: If the tree is wrapped with the linear explosives (FLE), the quantity becomes *n* x (24/12) = 6.3 feet (2 meters). This is a significantly smaller quantity than predictably needed, and it would therefore require at least six wraps to ensure that the tree would fall. Therefore, for every 4 inches (37 cm) in diameter, wrap the tree once with fireline (FLE) explosive.

Special Considerations

1. Place the detonator or det cord on the top of the pyramid of explosives to develop appropriate shock waves to fell the tree.
2. Where bark is unusually thick or loose, it should be removed from the tree before placement of the explosives. CAUTION: this may not be safe practice on some trees.

Tree Diameter (D) Inches	Tree Circumfrence (πD) Inches	Internal Load (D^2/250) lbs	External Load (D^2/40) lbs	External Load # 1 lb Sticks	External Feet of FLE in One Location	External Feet of FLE Wraps = Feet
8	25.0	0.27	1.6	2	3	2 = 4
12	37.7	0.60	3.6	4	6	3 = 9.5
16	50.3	1.07	6.4	7	11	4 = 17
20	62.8	1.67	10.0	10	17	5 = 26
24	75.3	2.40	14.4	15	24	6 = 38
28	88.0	3.26	19.6	20	33	* 7 = 52
32	100.5	4.27	25.6	26	43	* 8 = 67
36	113.1	5.40	32.4	33	54	* 9 = 85
40	125.6	6.67	40.0	40	67	* 10 = 104
44	138.2	8.07	48.4	49	81	* 11 = 127
48	150.8	9.60	57.6	58	96	* 12 = 151

* Not Recommended.

(Figure 9-31) Tree diameter and respective explosives loads.

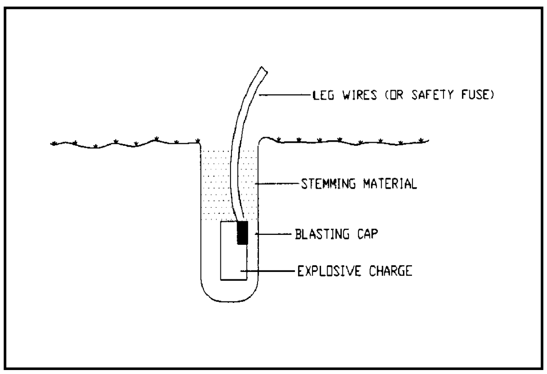
3. Always place the explosives on the "direction of fall" side of the tree unless the danger warrants otherwise. Never assume that a tree will fall in a given direction.
4. Assume that all blasts will produce flying debris.
5. Always adhere to the 500-foot (152-meter) distance rule.
6. Always use a detonation system that is not susceptible to the hazards of electromagnetic radiation (EBWs or nonel).
7. Use extreme care around hollow rotten trees. Spread explosives across the face of the tree to avoid blowing a hole through the center, which could leave the tree standing and extremely dangerous to approach the second time.
8. When in doubt, use more explosives than the formulas indicate, especially when wrapping large trees with linear fireline explosives.

9. Always follow the rules and practices given in the *Guide for Using, Storing, and Transporting Explosives and Blasting Materials* and on the instruction sheet in every box of explosives.

10. Take special precautions where burning trees may fall across burn control lines.

POST HOLE SHOOTING

Drill a single hole, 24" to 30" deep, large enough in which to fit the explosive. Place the cap in the explosive charge where, when inserted in the hole, the cap points toward the bottom of the hole. In hardpan or seamy rock formations, usually one-half of a stick of a good binary explosive will accomplish the task. In solid rock, one full stick is necessary.



(Figure 9-31) TPost hole shooting.

DRILLING HOLES

In rock formations, a hand-held rock drill is required. This equipment can be rented at most equipment rental stores. In hardpan or hard-packed ground, a digging bar or hand auger will usually be the cheapest and best way to punch a hole.

In many cases, fences are built close to dwellings, roads, etc. It is always advisable to cover a shot with some kind of material. Used conveyor belting, old bed springs, chain link fence, two feet of dirt, plywood, old tires, etc., make reasonably good blasting mats for this type of shooting.