ISEE - Journal of Explosives Engineering
Vol. 13 No. 7 July/August 1996
Back to Basics:
Electric Initiation Part 4

BACK TO THE BASICS

by Larry Schneider

Electric Initiation Part 4: Safety Considerations

A blaster, using electric initiation, must be aware of certain hazards specific to this type of system. Since electric detonators are designed to fire when electrical energy is applied to them, any extraneous source of electric current represents a potential premature initiation source. Therefore, such things as lightning, radio transmitters, high voltage power lines, or sources of static electricity must be avoided. Additionally, any condition which would cause a reduction in the applied current may result in insufficient firing current and create a misfire hazard; any condition producing an excessive current may result in hangfires.

Lightning

Lightning is considered to be the greatest danger associated with electric blasting. Nearly every blaster has either experienced this personally, or knows of such instances where lightning has set off a blast prematurely. Lightning is not required to strike a blasting circuit directly; even a near miss can set off any electric detonators. (Note: lightning represents a hazard to ALL types of blasting, including non-electric systems, while non-electric detonators may not be as sensitive to near misses, a direct hit by a lightning bolt will almost certainly cause them to initiate.) There are also instances of lightning traveling several miles underground along pipes and cables, setting off electric detonators.

Safety regulations and common sense require that whenever an electrical storm approaches, blasting operations must be suspended. Not only must operations cease, but the blasting crew must evacuate the area and clear the site of personnel and equipment, just as if detonation were imminent. There are devices available which are capable of detecting a storm's approach before it poses a threat to the blasting crew, and emitting a warning signal when a thunderstorm and lightning comes within a certain range.

High Voltage Power Transmission Lines

High voltage power lines present two distinct dangers to blasters using electric initiation systems. First, high voltage alternating current in the power line has the potential to produce a secondary current in the blasting circuit. This "induction" of electric current can take place in a blasting circuit without the blasting wires being in physical contact with the energy source. In addition, such high-voltage power lines may themselves suffer some current leakage which can introduce a "stray current" in the ground. There is test equipment available that can be used to measure any stray currents in the vicinity of a blasting site. Any significant source of extraneous current must be eliminated before electric detonators are used.

A second and even more direct danger to the blaster from high voltage lines is that of electrocution. This can occur if the detonation throws the leg wires or lead line up in the air and they come into contact with overhead high voltage lines. This type of accident, which should be so easy to foresee and prevent, has nevertheless occurred repeatedly in past years. To avoid such an accident, the blaster should either make sure that the total length of wires, (leg wires, connecting wire, plus firing line) is too short to hit the high voltage lines should they be thrown in the air; or the wires must be securely anchored to the ground so that they would break before they are thrown in the air and into any high voltage lines. If neither of these alternatives is feasible, a non-electric system should be used.

Radio Frequency Energy

Transmission from any two-way type of radio sends out energy in the form of electromagnetic waves. In a very real sense, the wires of a blasting circuit can act as an antennna, picking up radio frequency energy and converting it to electric energy in the blasting circuit.

The degree of danger that a radio transmitter poses depends on four criteria: (1) the frequency of the radio waves; (2) the output power (in watts) of the radio transmitter; (3) the distance from the transmitter to the blasting circuit; (4) the shape and the orientation of the blasting circuit. The Institute of Makers of Explosives publishes an excellent guide, entitled "Safety Guide to the Prevention of Radio Frequency Radiation Hazards in the Use of Commercial Detonators." Whenever any question arises concerning safety of blasting in the vicinity of a source of radio waves, the blaster should consult the IME publication. It provides tables listing safe distances from the specific radio sources. That is, if the frequency and the power of a radio transmitter are known, this publication will list a safe working distance.

A significant danger can exist when blasting near commercial AM, FM, or TV stations because of their large power output. Mobile radio transmitters in vehicles may pose a danger because they may approach very near to the blast site. Radar is also dangerous because of its highly directional nature of its beam.

On every new project using electric detonators, the blaster should survey the area for possible sources of radio energy. And even after the blasting operation is under way, he must remain aware of the danger from radio sources. Precautions must be taken to keep mobile transmitters away from the area, including posting the familiar road signs warning everyone to "Turn Off Two-Way Radios." If a source of radio frequency energy is found, and cannot be eliminated, or complying with the recommended distance is not possible, then switching to non-electric initiation is highly recommended.

Current Leakage

A blasting machine provides electrical energy in the form of voltage and current applied to the cap circuit. If a part of this firing current is lost during transmission through the firing cable, leg wires, or connecting wires, it is described as current leakage. The remaining electrical energy may be reduced to such a point that the current reaching the detonators in the circuit is below the level needed to reliably fire them, resulting in a partial or complete misfire.

This leakage or loss of current often occurs when bare electrical connections are allowed to come in contact with another conductor, or even with a conductive portion of the ground. Certain shales and clays are very good electrical conductors, especially when wet. Likewise, areas around the boreholes where Ammonium Nitrate-Fuel Oil has been spilled, or any puddle of water containing impurities will also conduct electricity.

To prevent current leakage from occurring or to minimize its impact, the following precautions can be taken:

- All bare wire connections should be kept as far apart as possible. The wire connections should be bent in such a fashion to keep the bare metal up out of dirt and water.
- The number of electric detonators in any circuit should be kept below the recommended maximum per series so that the circuit will have power to spare in the event there is a small leakage of current.
- Only enough insulation should be removed from the wires as necessary to make the connections.
- The blaster should routinely check the insulation on his firing cable for cuts or damage. Any splices made to repair breaks in a firing cable should be well insulated.

Arcing

When an excessive current is applied for an excessively long time, an electric detonator will likely malfunction by rupturing before the base charge fires. If arcing occurs and the detonator ruptures, the explosive in which the detonator is embedded may catch fire. This is known as a "hangfire" where the explosive in the borehole begins burning, and eventually may detonate. This detonation may take place a few seconds after the blast was fired or a few minutes later. Due to this delayed detonation of hangfires, no one should approach a misfired charge for at least 15 minutes after a shot is fired electrically. The best way to avert any danger from arcing is to use a condenser-discharge-type blasting machine. These machines deliver their energy in a very brief time interval, too short for arcing to occur. The use of batteries, generators, or ordinary electric lines may produce a continuous high firing current and result in arcing.

Firing the Blast

After all the boreholes are loaded, the detonators are wired into a circuit to form an initiation path. Care must be taken to see that all detonators are connected into this circuit; omitting any will result in a partial misfire putting unexploded charges in the muck pile.

Blasting machines must be kept clean and in good working order with fresh batteries in order to provide their rated output. Except for replacing batteries, a blaster should never attempt to work on his blasting machine. If it is in need of repair, it should be returned to the manufacturer or an authorized service facility. The blaster should never attempt to initiate an electric blasting circuit with anything other than a power source specifically designed for electric blasting. The use of makeshift energy sources, such as automobile or flashlight batteries, is dangerous in that misfires or hangfires may occur.

When the blaster takes his position to fire the shot, he alone should have control of the blasting machine. Prior to connecting the firing line to the blasting machine, he should make one final check of resistance and continuity of the blasting circuit. The firing cable should not be connected to the blasting machine until he is ready to detonate the blast. Upon hearing the final warning signal, the blaster should wait the predetermined time, connect the firing line, and detonate the shot. Immediately after the shot is fired, the lead line should be disconnected from the blasting machine and shorted.

ISEE- Journal of Explosives Engineering- Vol. 13 No. 1
July/August 1995
Back to Basics: Nonelectric Initiation Shock Tube
Systems – Part 1 General Description

Back to the Basics: NONELECTRIC INITIATION SHOCK TUBE SYSTEM% PART 1 GENERAL DESCRIPTION

by
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Over the past eight to ten years, there has been a significant growth in the number of operations using nonelectric initiation systems of initiation. While safety fuse and detonating cord have existed for many years, and both are certainly nonelectric methods of initiation, this modern trend toward nonelectric initiation is primarily due to the development and the widespread acceptance of the various shock tube systems.

Shock tube was first introduced commercially to the mining and construction industry in the United States in the mid 1970s. At first, these nonelectric systems were presented as a safer alternative to the familiar electric blasting caps. Since they were insensitive to radio frequency energy as well as any source of static or stray electric currents that are found in normal mining or construction sites, they could be safely used in areas where these hazardous conditions existed.

However, it was the shock tube's ability to allow the blaster to design a shot with nearly an unlimited number of delay periods that fueled their increasing popularity. Shock tube and the various associated elements in this system can be utilized in many different ways to produce assorted delay patterns. By combining surface delays and down-the-hole delay detonators, blasts with a large number of boreholes can be detonated so that each borehole, or even each of several deck charges in the boreholes, will all fire within their own delay interval.

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According to the ISEE's *Pocket Guide to Explosives Products*, there are four brands of nonelectric shock tube systems currently available in the United States and Canada. These are: Austin Powder's Shock Star System, Dyno Nobel's Nonel Super System, Ensign-Bickford's Primadet Series, and ICI Explosive's Excel System. While all these systems are based upon the same fundamental principles as the original Nitro Nobel system, the specific components in the systems vary from manufacturer to manufacturer. The chief differences in these various systems exist in the construction of the detonator, the type of surface delay blocks, and the type of connections used.

Due to various methods of connection and the differences in recommended procedures, it is vitally important that before a blaster uses any of these systems, he is thoroughly trained and familiar with the proper use of that particular system.

The shock tube itself consists of a small diameter plastic tube coated on the inside with a very thin layer of reactive material. This tubing acts as a path which transmits a "detonation signal" from detonator to detonator. This detonation signal can be delayed by elements inserted into the path; and delay elements in the detonators also provide timing delays before firing.

The plastic tube is made with sufficient tensile strength and abrasion-resistance so it can withstand the rugged conditions that it is routinely exposed to in the boreholes and on the surface. Most manufacturers also "color-code" this tubing as a means of differentiating between the various type of products available, such as surface delays and down-hole detonators.

The tubing is sealed to prevent any contamination from entering and desensitizing the reactive material. Likewise to prevent the tubing from malfunction, the tubing should never be cut open, Nor should it be spliced together to form longer or shorter units unless the manufacturer provides special connections to do so. To provide for the variety of borehole depths and pattern spacings, the detonators and their attached shock tubes are available in a wide variety of lengths from the manufacturers.

Once the tube is initiated, this reactive material "explodes" and propagates a shock wave which travels at between 6,000 and 7,000 feet per second (1,800-2,100 meters/second) down the tube. This shock wave phenomenon inside the tube is similar in nature to a dust explosion and will propagate reliably though all but the most severe of bends, knots or kinks in the tube. While 6000 feet/second sounds like a high velocity, in explosives terms this shock wave propagation velocity is relatively slow. This means that travel time or transmission time of the shock wave must be considered when designating the delay time for any units with tubing attached. For example this shock wave traveling through **44** feet **(13.5** meters) of tubing takes 8 milliseconds. The manufacturer must and does incorporate this travel time into the delay time designations of all elements with a significant length of shock tube. Units cannot be shortened without affecting the delay time as listed on the component. For critical applications, the manufacturer should be consulted for advice on the actual firing times to be expected with detonators of various tubing length.

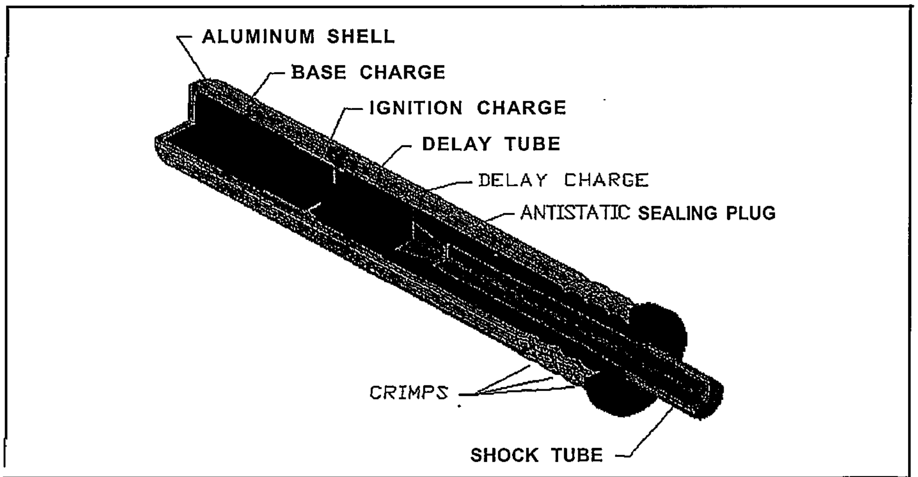
Unlike detonating cord, which acts as a detonator along its entire length and has a disadvantage of being noisy, the shock tube has an extremely small quantity of reactive material in it and the shock wave is confined inside the tubing. Since the outer surface of the tubing is unaffected, there is no noise associated with the detonation of the tubing. Even though the tubing itself generates no noise, that is not true of the surface delay connections. These units can produce significant noise unless they are well-covered with drill cuttings or loose earth.

Since the tube itself remains intact during initiation, obviously the shock wave traveling inside it can have no effect on any other explosive materials with which it may come in contact. Likewise, this shock wave cannot be transmitted from one tube to another by merely tying them together. These two characteristics mark the most obvious contrast with detonating cord used as trunklines or downlines.

Since the tubing will not initiate high explosives, a detonator or cap must be used.

This detonator is factory-assembled to the shock tube and the elements inside the detonator convert the shock wave signal to a detonation. The detonator contains an ignition charge, a delay charge when applicable, and a base charge of sufficient strength to initiate any high explosive it contacts (see Figure **1**, below).

The author wishes to thank: John ***Capers, Austin Powder Co.; Dick*** *Gotcher, The Ensign-Bickford* ***Co.;*** Bob *Hopler, Dyno-Nobel* Inc.; and ***David Smith, ICI Explosives USA; for their assistance in reviewing this material; and Carlos Delgado, Kentucky Dept. of Mines and Minerals, for his artwork. - LS.***



ISEE -Journal of Explosives Engineering-Vol. 13 No. 2- September/October/1995- Back to Basics: Nonelectric Initiation Shock Tube Systems –
Part 2 General Applications

BACK TO THE BASICS NONELECTRIC INITIATION SHOCK TUBE SYSTEMS, PART 2: GENERAL APPLICATIONS

by
Larry Schneider

In the simplest application of a shock tube initiation system, the tubing acts as a "relay line" which passes a detonation signal from borehole to borehole. When the signal arrives at each borehole, it causes the detonator attached to it to fire. Such a single path constitutes a progressive series where each unit must function properly in order to activate the following units. Any application error, malfunction, or mistake in connecting any surface unit will stop the progression of the detonation signal through the system and result in a "cutoff" or misfire of the following charges.

One of the most basic methods used to create timing delays in such shock tube systems is by means of surface delay connectors. These connectors detain the firing signal for a preset length of time as it travels from one borehole to the next. A second method of creating timing delays is through the use of in-hole delay detonators. These have a pyrotechnic delay element built into the detonator, which produces a specific time delay between the time the detonator receives the initiation signal and the time the base charge in the detonator explodes.

In most practical instances, blasts are designed with both surface and in-hole delays in order to produce an effective delay pattern.

As emphasized in Part 1 (July/August, 1995) of this series, the various manufacturers of the shock tube systems have different components with different time delays, methods of connecting, and recommended procedures and patterns. Due to these differences, it is vitally important that the blasters be thoroughly trained and familiar with the proper use of the system that they will be using. The following patterns are described merely as examples of the fundamental principles of shock tube patterns and are in no way recommended as patterns to be used in actual blasting with specific systems.

Figure 1 shows a single row of boreholes with 17 millisecond surface delay connectors inserted between each. As the detonation signal travels down the tubing from the point of initiation to each borehole, it is delayed by each surface connector. Assuming the in-hole detonators have no built-in delays, the explosive charges in the borehole will fire at the instant that the detonation signal from the tubing reaches the detonator in the borehole. While the example uses a 17 millisecond surface delay connector,

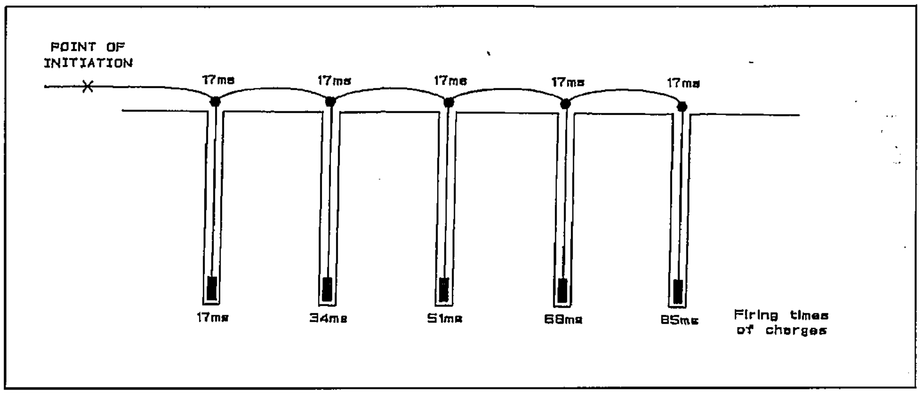


Figure 1. A single row of boreboles with 17 millisecond surface delay connectors inserted between each.

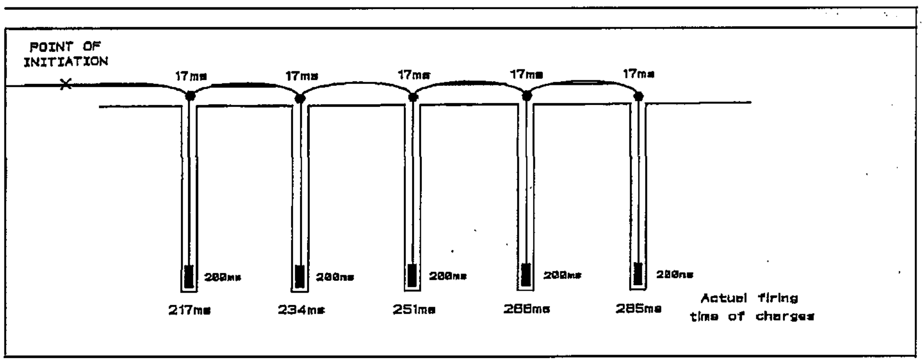


Figure 2. If an in-hole delay is added to each hole in the samepattern as Figure 1 and shown here, the actualfiring time of the charges *will be the sum of the in-hole delay time plus the time it takes for the firing signal to reach the detonator in the borehole.*

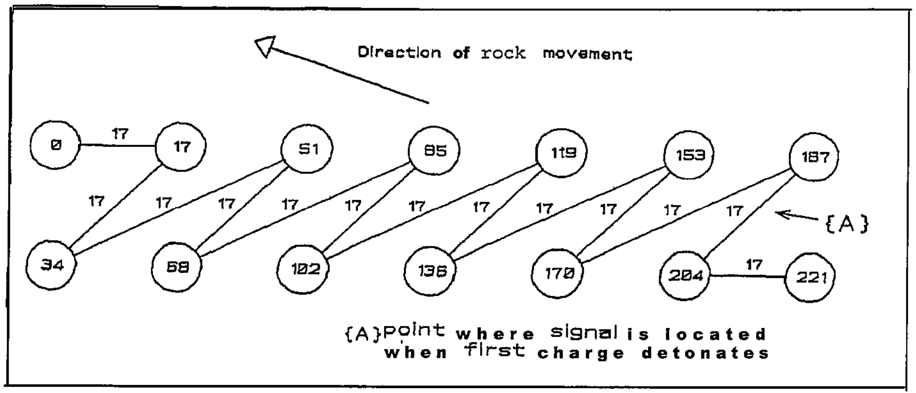


Figure 3. The boreholes are connected with 1 7 millisecond surface delay connectors, and each borehole has a 200 *millisecond in-bole delay.*

other values are available depending on the manufacturer; such as 25 ms, 42 ms, or 100 ms, etc.

If an in-hole delay is added to each hole in the same pattern as Figure 1 and shown in Figure 2, the actual firing time of the charges will be the sum of the in-hole delay time plus the time it takes for the firing signal to reach the detonator in the borehole. If the same in-hole delay period is used in every hole, the duration of the blast is exactly the same as if there were no in-hole delay, though its starting time will be set back by the value of the in-hole delay.

While the previous patterns showed a single row of only 5 boreholes, this pattern and method of delaying the individual charges could be extended indefinitely in length and every charge would be separated by 17 milliseconds.

To provide a continuous progression through the pattern as well as initiate the charges in the boreholes, each element in the "hookup" must initiate at least two following units. The shock tubing, carrying the incoming detonation signal must be attached to an in-hole detonator in order to transmit the signal down the borehole to the detonator embedded in an explosive charge. It must also be connected to a second unit, a surface connection which will continue to carry the detonation signal to the next borehole.

By combining surface delays and in-hole delays with different values, the blaster can create a variety of blast timing patterns. In the pattern in Figure 3, the boreholes are connected with 17 millisecond surface delay connectors, and each borehole has a 200 millisecond in-hole delay. When the initiation is started at the first hole on the left in the diagram, the detonation signal travels through the system and each hole receives the firing signal 17 milliseconds after the previous one. In this example, the tubing is alternately connected from front to back row to create an echelon-type delay pattern. The top number in each circle representing the borehole is the time in milliseconds when the firing signal reaches the borehole, the bottom number in the circle is the actual detonation time of the charge in that borehole.

Another significant advantage is gained by placing a delay in the borehole. With the in-hole delay, the signal, *traveling in* the tubing on the surface, has time to move away from the vicinity of the rock that may be disrupted by the detonation of the charge in the borehole. This reduces the possibility of cutoffs of the detonation signal due to ground movement breaking the tubing. In the example shown in Figure 3, the actual signal in the tubing is located at a point between the twelfth and thirteenth hole when the first charge detonates. Therefore, it is well away from any ground movement due to the detonation of the first charge. In fact, before the third charge fires (234 ms), the shock tube signal has reached the last hole (221 ms) and completed its initiation sequence.

When the same in-hole delay is loaded in each borehole of a shot, the blaster can direct the movement of the rock by changing the progression of the surface delays and/or the point of initiation. Since this is done by placement of the surface elements, it is possible to change the direction and movement of the rock even after the boreholes have been loaded and stemmed by rearranging the surface delays.

A simple illustration of changing the rock movement by altering the point of initiation in the pattern is shown by comparing Figure 4 to Figure 3. By adding 42 ms surface con-

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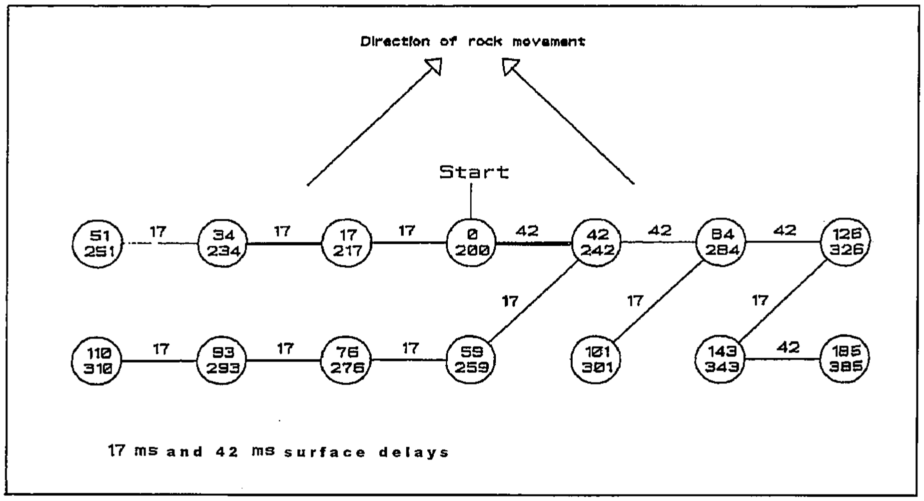

Figure 4. A simple illustration of changing the rock movement by altering the point of initiation in the pattern is shown by comparing this figure to Figure 3.

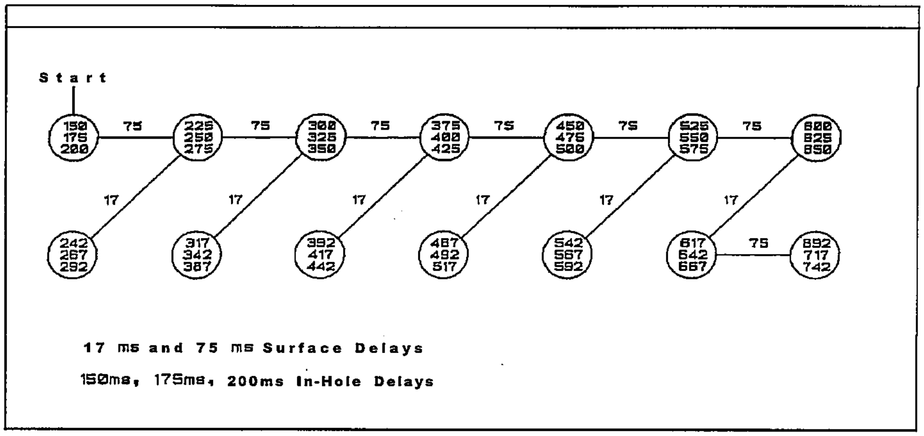

Figure 5. When decking is necessary in a blast design, it can be accomplished by placing two different in-hole delays in each borehole, and initiating them with the same incoming signal.

nectors to the right side of the pattern and initiating the center of the blast first, the rock movement is directed from both ends of the pattern toward the middle.

When decking is necessary in a blast design, it can be accomplished by placing two different in-hole delays in each borehole, and initiating them with the same incoming signal. Figure 5 shows such a blast pattern. Each borehole has three separate deck charges, with in-hole delays of 150 ms, 175 ms, and 200 ms, and are connected with surface delays of 17 ms and 75 ms. The numbers in the circles representing the boreholes indicate the firing times of the three decks placed in the boreholes. A pattern such as the one shown can be extended indefinitely in length, but if more than three rows are used, overlapping delay times will occur.

By use of these principles, blasts with hundreds of charges can be detonated, each in their own individual delay interval. Such delay intervals are usually required to have at least 8 milliseconds between the charges in order to comply with blasting regulations. However, while it is theoretically possible for some delay blast patterns to continue with no limit on the number of holes, many multi-row patterns are often limited in their scope. When delay blasting with these non-electric delay elements, the blaster must select the proper combination of delays and pattern and check the progression of the detonation carefully before firing the shot. Even before using a pattern recommended by an explosive manufacturer, the blaster should sit down with a pencil and paper and calculate exactly when each charge is designed to fire. His review of the firing times should determine whether or not there is an excess number of charges firing within an individual delay interval.

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BACK TO THE BASICS

by Larry Schneider

Flyrock (Part 2: Prevention

In part one of this series on flyrock seven common causes of flyrock were listed. The first cause was described as an excessive amount of explosives. When you hear that description, the implication is that the blaster loaded "TOO MUCH EXPLOSIVES IN THE HOLE." In fact, this is what the public often accuses blasters of, whenever they have a complaint about the ground vibration, noise or flyrock; that is, the blaster deliberately put too much powder in the hole. As the blasters themselves are well aware, that explanation is too simplistic because there is only a certain amount of explosives that will fit into a borehole of a particular diameter and depth. Furthermore, due to the economics of blasting, the idea is certainly not to use any more explosives than necessary.

So the statement that there was an excessive charge in a blast usually means that there may be some other problems, such as the blast was loaded with a powder factor (as measured in lb of explosives per yard^3 of rock) that was too large for the type of rock being shot. A powder factor that is too high can cause enormous movement of the rock. And an excessively large powder factor can actually occur due to any of several of the causes described in the list. For instance, if the burden distance is too small for the borehole diameter, or if not enough stemming is loaded in the borehole, those factors also result in an excessive powder factor and an overloaded blast.

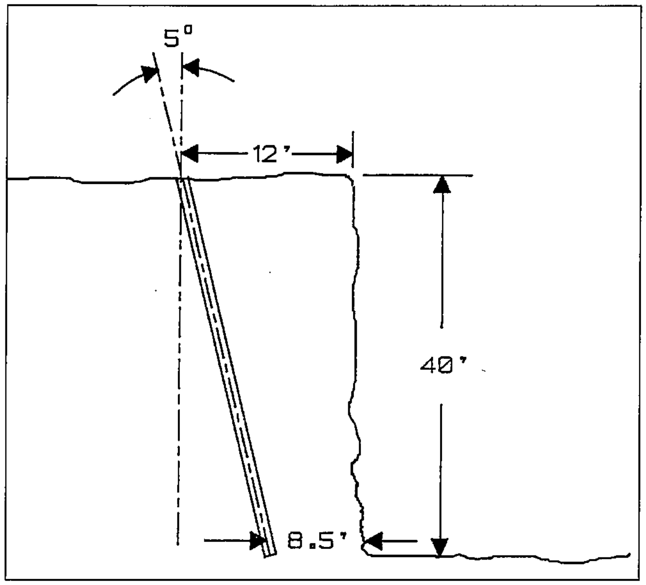

Figure 1

This may result from poor design when planning the burden or spacing. Or sometimes, poor execution in the field occurs when trying to implement a good blast design. For instance, a blaster may load a hole where the powder factor has been calculated correctly for a given burden, spacing and depth, but the boreholes were not drilled accurately according to that design. The blaster must also be aware of what the true burden is on each borehole, and whether or not that burden is consistent through the length of the borehole. Note that the true burden is determined by the delay timing sequence as well as the blast geometry.

If we look at some of the following diagrams, we can see in some cases clearly where the burden turns out to be less than that which the blaster expected. In figure 1, the bench has a good vertical free face, but the drilling was done poorly. If the blaster proceeds to load the borehole for the 12 foot burden he has at the top, he will be overloading the bottom of the hole where he has only 8.5 ft. An inaccuracy such as this, when the drill is off the vertical, will be magnified the deeper the borehole is drilled. As an example, a borehole 40 feet deep, which is drilled 5 degrees from the vertical results in an error of 3.5 feet at the bottom of the hole. The same borehole drilled 100 feet deep with the same 5 degree error, will be off by nearly 9 feet at the bottom of the hole. Even in the first instance, where the burden was off by 3.5 feet, the powder factor may vary by 20% from top to bottom of the borehole.

As an example of this type of error, consider a blaster who intends to drill a 12 x 15 pattern, 40 feet deep, using 8 ft of stemming in a 51/2 inch diameter, and loads it with a loading factor of 8.25 pounds of ANFO per foot. With this pattern, he expects to have an average powder factor of 1.00 lb/yd^3 for the borehole. If, however, the driller errs by 5 degrees from the vertical, his burden at the bottom is only 8.5 ft., and his average burden throughout the borehole would be 10.25 feet. His actual powder factor for the entire hole will be 1.16 lb/yd. Even more striking, is the fact that while the powder factor for the top one foot of the powder column is 1.29, the powder factor at the bottom of the borehole is 1.75 lb/yd, an increase of more than 35%.

Figure 2 shows a perfectly drilled vertical hole on a level bench, but due to the equipment excavating material at the front of the bench, the blaster may encounter a bench with a profile like this. In this example, if the blaster does not check the shape of the free face, he may load the shot for a 15 ft burden and only have 8 feet of rock confining his explosive charge.

A similar instance is where the holes are "buffered" in front of the shot, and the blaster drills near the free face to ensure that he "pulls the toe." The profile may look like the one shown in figure 3. The first row of hole is drilled close to the crest since there is a large buffer that reaches nearly to the top of the bench. Subsequent rows of holes are set back a reasonable distance, and the blaster assumes that the buffer will confine the blast on the outside boreholes. And it may work as planned provided the powder column is not loaded too high, so that the top portion of the charge is not near or above the buffer. If a charge is loaded such that the charge is unconfined in this top portion, it can throw rocks over a long distance.

Accuracy in drilling is extremely important when angled holes are used. The setup distance from the face, the angle of the drill must be measured carefully to ensure that the proper burden exists at the toe. Failure to do so can result in charges that are placed too close to the face with less confinement than intended.

If explosives are loaded into faults, crevices, or mud seams that the borehole passes through, the blaster should expect excessive flyrock. The driller has a crucial role to play in the preparation of the blast. Information about any unusual conditions such as mud seams or voids encountered in the borehole must be recorded or logged, and the blaster must rely on his driller to communicate any unusual conditions of

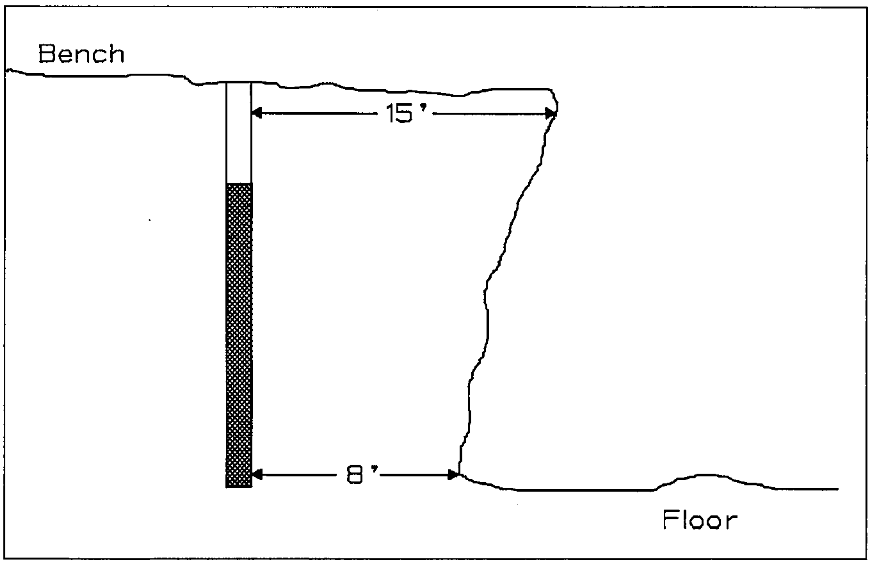

Figure 2

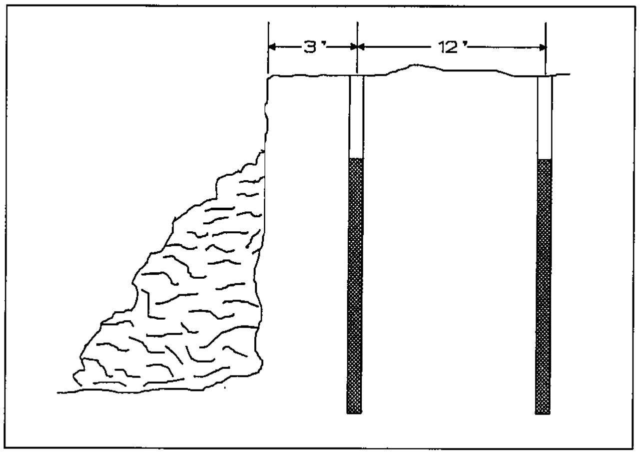

Figure 3

the boreholes he has drilled. The driller must be constantly aware of what is happening as he drills, so he will know if he encounters a significant mud seam or a void such as a cavern or an abandoned underground mine.

If explosives are loaded into a mud seam, the mud does not have sufficient resistance to confine the energy of the detonation. As long as the blaster knows in advance that a mud seam intersects the borehole, he can take steps to eliminate the danger. This is normally done by stemming through the mud with inert material to make two separate charges in the borehole. A cardinal rule for a blaster is that explosives should never be loaded into anything except competent rock.

Likewise, if a borehole is drilled so that it cuts into a cavern or underground mine, the blaster may load huge amounts of explosives, and if detonated will create a violent result. If the blaster is careless while loading the borehole, especially when using bulk explosives, he may not detect the fact that a large amount of explosives are going into the borehole. It is always important that a blaster constantly monitors the rise of the powder column in the borehole using a tape or other method.

Adequate stemming is required to confine the high pressure gases released by the detonation of the explosive charge. This stemming must be sufficient to prevent the force of these gases from violently cratering to the surface. The explosive force will always be in the direction of least resistance, which should be the burden distance to the free face at the instant of detonation. However, if the stemming length is too small, the most direct path for the gas pressure to vent may be to the surface. In minor occurrences, this results in stemming material being launched away from the blast. More serious cases occur when material around the collar of the borehole can be thrown significant distances.

Adequate stemming does not only mean the length of the stemming, but also the composition of the material used as stemming. Drill cuttings or dust are usually a very poor stemming material, particularly if the borehole is water-filled. Crushed stone of a suitable size so that it interlocks in the borehole is a recommended stemming material on most operations.

Another potential problem occurs if a blast pattern is drilled such that the spacing and burden is greater than the borehole depth. In this situation, the blaster should expect flyrock. Blasters occasionally drill this type of pattern without realizing that they are creating a potential hazard. For example, a blaster using a 6 3/4 inch drill bit tries to blast an excavation to grade that is only 8 feet deep. He may be conscientious enough to realize that he only needs 2 feet of powder in a borehole drilled on a 12 x 14 feet pattern, 8 feet deep to get a proper powder factor. However, such a design produces a burden greater than depth, so that the nearest direction for relief is the surface, and rock may be thrown straight up into the air.

Certain operations use blasting patterns where the burdens are sometimes close to, or slightly greater than the depth. One of these are the "parting shots" in surface coal mines, where the blaster has to break a layer of rock that lies between two coal seams, this strata of rock may be anywhere from 8 to 20 feet thick and the blaster may have to use a large diameter drill with a 12 x 12 pattern. It can result in a great deal of material thrown, but usually such blasts are a large distance from houses, and roads.

Occasionally blasters in quarries are required to shoot "toe shots" where they come back after the main blasts have failed to pull to grade. On these shots, the boreholes may be drilled in an irregular pattern and very shallow. When they are fired, flyrock is a definite possibility. So called "lift shots" or any shots fired to begin an excavation are also prone to generate flyrock. These shots have no free face and are intended to cause the rock to fragment and swell. However, if they are not carefully loaded and controlled, the fragmented rock again is launched upward. On smaller scale blasts, such as those for setting electric utility poles, the use of "burn or cut" holes serve to provide a place for the bro-

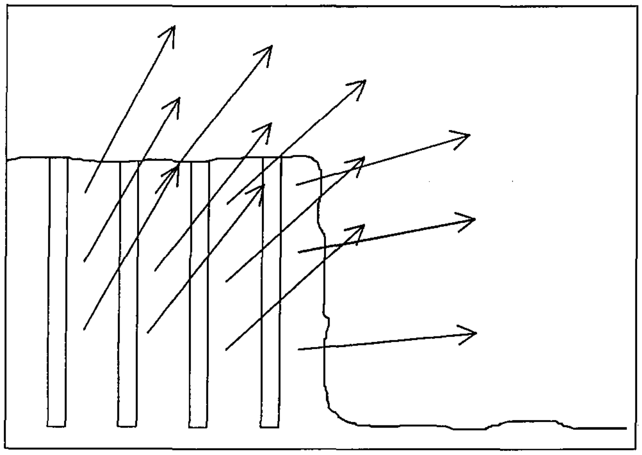

Figure 4

ken rock to move and help control the upward throw. On these shots, blasting mats may be useful, but a good blast design is still critical.

Poor delay timing can generate flyrock. Faulty delay time may be the result of bad design, but could also be caused by inaccurate detonator firing time, or simply human error in laying out the delay detonators. The timing on all shots must allow enough time for the rock to move so the muck does not pile up in front and prevent the intended horizontal movement of subsequent charges. Figure 4 shows the effect that takes place as the detonation proceeds deeper into the bench if there is insufficient time for the rock in front to move. That is, the movement of the rock from each borehole progressively moves upward at an increased angle until the back rows become almost a lift shot and the rock movement is close to vertical. Normally this can be somewhat corrected by providing longer delays between the rows as the shot progresses deeper into the pattern.

Figure 5 shows a delay pattern which illustrates a very simple type of timing delay that results in the same effect. In this case, a mistake has occurred and a #10 delay is misplaced in the shot pattern. When this shot is detonated, the charge in that hole will fire with no relief at all and the only possible movement of the rock around it will be vertical. A blaster would be incompetent if he laid out a shot like that on purpose, and at the very least, careless if he did it by accident. However, with complex timing layouts, both electric and non-electric, any error in the connections can result in holes firing out of sequence. The timing mistake may not be as blatant as the one illustrated to have the same effect.

Regulations usually require that when blasting is done in proximity to buildings and roads where no amount of thrown material can be tolerated, blasting mats or other protective materials should be used to confine any possible flyrock. But even in those cases, the best means of controlling flyrock is still through proper blast design and delay timing. It is therefore extremely important that when a blaster working with a successful blasting program makes any change in the blast design, he must carefully consider any changes from the standpoint of its potential effect on flyrock. While many of the causes of flyrock mentioned previously can be predicted and avoided, it is always possible that there exists some unknown condition that will cause flyrock. For this reason, the blaster must always assume the worst possibility and formulate his plans to clear the area for this case. Regardless of how many "well-behaved" shots he has previously detonated, the next detonation is always the most dangerous.

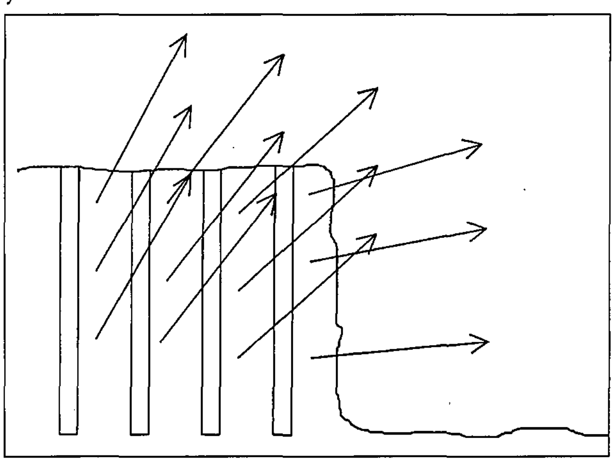

Figure 5

It is the ultimate responsibility of every blaster to oversee the safety and well-being of anyone that could be effected by the blast. They must accept this responsibility and do whatever it takes to protect the public, their co-workers, and themselves.

While the explosive products we use today are the safest, most reliable ever produced, they are only as safe as the individuals using them. Training and education in all aspects of blast safety must always take high priority in our industry, as well as accountability and responsibility in implementing the procedures that are learned.

ISEE- Journal of Explosives
Engineering- Vol. 13 No. 3
November / December 1995
Back to Basics: Nonelectric Initiation
Shock Tube Systems -
Part 3 Safety Considerations

BACK TO THE BASICS
Nonelectric Initiation Shock Tube Systems
Part 3: Safety Considerations

by
Larry Schneider

One of the incentives that led to the development of non-electric shock tube initiation systems was the desire within the industry to improve detonator safety. And to the extent that nonelectric initiators are immune to the hazards of stray current and radio frequency energy found on normal blast sites, an advancement in safety has been accomplished. However, as a cautionary note, it is important to realize that there are still many hazards associated with any initiation system. While some of these hazards may differ from those associated with electric detonators, others are identical to those associated with any type of initiation system. For instance, contrary to what some uninformed blasters may believe, lightning remains a hazard when using nonelectric initiation as well as electric initiation. A direct lightning strike will provide enough energy to detonate shock tube, and this has been clearly demonstrated in a number of cases on actual blasting sites. The rules regarding blasting and thunderstorms remain the same regardless of the type of initiation used-that is, whenever an electric storm approaches, blasting operations must cease and the area must be cleared.

Likewise, since the detonator attached to the end of the tubing contains sensitive ignition and base charges, it is susceptible to heat and impact and must be protected from abuse just as any other type of detonator. The plastic tubes which carry the firing signal are subject to damage from equipment and mishandling during loading just as the leg wires are in electric caps.

These products are explosives and as one major manufacturer states in their disclaimer: "Use of these products by anyone who lacks adequate training, experience, and supervision may KILL or INJURE."

The need for suitable training and experience with nonelectric initiators is especially true because of the wide variety of systems available and the procedures and methods unique to each one. The fact that a blaster is knowledgeable about the particular nonelectric system he is using does not necessarily qualify him with any other system.

Likewise, the various systems are not compatible with one another and components from different types of systems should never be mixed in a single blast unless specifically approved by the manufacturers.

Particular care must be exercised during the hookup procedures, since any error in making surface connections will result in a "cutoff." Since the only checks for continuity of these nonelectric "hookups" is through visual inspection, the success of the nonelectric initiation system depends heavily on the blaster's qualifications and skill. Additionally, it is vital that all the hookup work is done in a systematic and orderly fashion. As noted earlier, omitting a charge or failing to make a connection will result in a misfire, and handling misfires is dangerous.

Some surface delay components produce metal and plastic shrapnel when detonated.

The blaster should follow the manufacturer's directions closely in order to prevent this flying debris from causing cutoffs or damaging other components in the initiation system. Often this entails simply covering these surface units with adequate dirt or drill cuttings so as to confine the shrapnel.

Due to some of the reasons mentioned previously, there are a number of operations that have switched from electric blasting to nonelectric initiation, and have found that misfires have become more frequent. And, unfortunately, some misguided blasters may treat these misfires as a routine problem. Such blasters may have a tendency to become complacent with misfires using nonelectric systems because when such misfires are due to an application error on the surface, they usually can simply reconnect the charges and refire the shot. However, misfires can have very serious consequences and it is important that the blaster be aware of those consequences. Regardless of the type of detonators used, the blaster should take all steps possible to eliminate the chance of misfires.

On a blast site, care must be taken so that vehicles, such as bulk trucks, do not drive over the tubing, connectors, or any surface components. At a minimum, such action can damage the shock tubing and may result in a misfire. At worst, it can result in a premature detonation causing injury or death. There has been at least one recent serious accident that occurred as a result of a blaster driving over shock tube on the surface at a blast site causing the explosive charge in the borehole to detonate prematurely.

When the blaster prepares to connect the nonelectric system, no tools should ever be used to pry on any component containing a detonator. Nor should any tool be used to open, close, fasten, or clean out any connector containing a detonator or detonating device unless specifically designed for that purpose by the manufacturer of the detonating system. Components of these initiation systems should be used as originally manufactured and for the purpose they were designed; attempts to modify or alter any of these parts should never be attempted. If any components are found to be defective, damaged, or incompatible, they should not be used, but rather returned to the manufacturer.

In the past few years, nonelectric systems have been refined by the explosive manufacturers to improve the simplicity of the hookups, increase the tensile strength of the tubing, reduce the necessity of maintaining large inventories of different delays, and provide some measure of misfire prevention through double firing loops or paths. Furthermore, the plastic tubing on the surface is essentially noiseless when contrasted to the older detonating cord trunklines. Despite all these improvements, *these materials are detonators and* must be handled with *the same care and respect* as **any** *explosive.* Products which are designed to detonate can never be treated casually. They will always represent a potential hazard that must be carefully handled and closely controlled.

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ISEE - Journal of Explosives Engineering-
Vol. 14 No. 2 March/April 1997
Back to Basics: The Use of ANFO on Surface Blasting Operations

BACK TO THE BASICS

by Larry Schneider

The Use of ANFO on Surface Blasting Operations

Since its development in the mid 1950's, ANFO, which is a mixture of 94% Ammonium Nitrate and 6% Fuel Oil, has become the explosive of choice for many blasters working on large scale blasting operations. The stability and economy of this blasting agent has brought it to the forefront in both mining and heavy construction. Additionally, the advantages of the bulk mixing of the ammonium nitrate prills and liquid fuel oil on site, and loading directly into the boreholes, provides safer handling and quicker loading.

While ammonium nitrate (AN) is also used extensively in the formulation of some high explosives, emulsions, and water gels, the discussion in this article centers on its most common form, that of a prill to be mixed with fuel oil and used as a blasting agent. These "prills" are porous, spherical shaped pellets, typically between 6 and 20 mesh U.S. standard screen size. The porosity of the prills is carefully controlled during the manufacture of the AN prills to ensure that they will absorb the correct amount of fuel oil. This porosity is one difference between the blasting grade AN prill and the more common fertilizer grade AN used in agriculture. Another distinction is that the agricultural prill is much harder and has a higher density. Additionally there are different types and amounts of coatings used on the blasting grade prills to add a certain amount of water resistance, thereby preventing caking and allowing them to flow freely. The caking of this prilled material is due to the AN prill's tendency to absorb moisture from its environment. Without such a coating, AN will attract moisture from the humidity of the air and in effect dissolve itself.

Information from the U. S. Department of Interior showed that in 1993, ANFO blasting agents and unprocessed ammonium nitrate accounted for 83% of the total industrial explosives sold for consumption in the United States. Of the more than 800 million pounds of explosives used annually in the state of Kentucky, over 90% of it is ANFO which is detonated primarily in the surface coal mines.

As referenced earlier, the reasons for ANFO's widespread use are twofold:

1. It is safer than high explosives to handle, transport, and store. And because of its reduced sensitivity, regulations governing the storage and transportation of ANFO are not as stringent as those governing high explosives.
2. It is economical, beginning with a much lower cost per pound than any other explosives. In addition to its low cost, it has good rock breaking ability with a relatively high detonation velocity in large diameter boreholes, and large gas production during detonation. Under many conditions, its performance/cost ratio makes other explosive materials uncompetitive.

However, its performance as an explosive does vary based on a number of factors, some of which are controllable, while others are not. These factors are:

1. The physical characteristics of the prills, such as size, shape, porosity and density.
2. The distribution and proportion of the fuel oil when mixed with the prills.
3. The diameter of the borehole and degree of confinement.
4. The size and type of primer and the priming procedure used.
5. The exposure to water in the boreholes.

When the performance of the explosive is negatively affected, the blaster is very likely to know by observation of orange-brown smoke generated during the detonation. A blast which exhibits large quantities of such smoke or fumes may have been rendered inefficient for any one of the reasons in the list above.

The initial physical characteristics of the AN prills are determined during the manufacturing process, and the blasters must rely on their suppliers for good product. However, once the prills are on site, they are subject to a phenomena called cycling. Cycling is a process whereby AN undergoes a change in its crystal structure in response to a change in temperature. There are two temperatures, at which AN goes through this cycling, 0° F and 90° F (-18° C and 32° C). Both of these temperatures are readily reached by products stored in outdoor magazines during the winter and summer in most areas. The actual "cycling" occurs when the temperature fluctuates above and below these critical temperatures.

The effect of this change in crystalline structure is to break the prills down into smaller and smaller particles. This increases the density of the ANFO, and also diminishes the prills' water resistance, which is supplied by its coating. Over time, this will result in the AN drawing moisture from the humidity in the air, dissolving and reforming as larger crystals. Significant caking may occur in the bags or bins if it is stored for long periods of time as the temperature fluctuates around 0° or 90°. ANFO that has "caked" will detonate unreliably or inefficiently, and will present problems when loading.

The energy released by the detonation of ANFO is markedly effected by the percentage of fuel oil in the mixture. The energy release of ANFO is maximized when fuel oil content is 5.7 % by weight. Since the prill is porous, voids in it to allow it to readily absorb that amount of fuel oil. To further ensure the performance of ANFO, it is critical that the right amount of fuel oil be added uniformly and distributed throughout the mixture, regardless of whether it is done on site, in the bulk trucks or at the plant.

The detonation velocity of ANFO is determined by both the borehole diameter and the degree of confinement. As can be seen from **Figure 1**, the detonation velocity is highly dependent upon borehole diameter. While crushed prills can be detonated in boreholes as small as 1 inch in diameter, the normal ANFO prill requires a borehole diameter of 2 inches or greater to reliably detonate. As the borehole diameter increases to about 10 inches, the detonation velocity also increases until it is approximately 14,700 feet per second (4480 meters/second). Any increase in borehole dimensions beyond this, has little or no effect on the detonation velocity.

Likewise the confinement of the explosive during detonation is crucial in maintaining the detonation velocity. Any premature loss of pressure in the borehole, due to rock movement or venting, will result in a decrease in detonation velocity. Most blasters feel that the detonation velocity is one of the most important considerations in selecting an explosive. This is especially true when trying to fragment hard, massive rock strata.

By its definition as a blasting agent, ANFO is not "cap sensitive" and therefore requires a high explosive "primer" to initiate it. Such a primer must supply adequate energy, both as shock and pressure, to reliably initiate the blasting agent. An efficient primer will force the blasting agent to reach its steady state velocity in as short a time as possible. Steady state velocity refers to the detonation velocity at which an explosive or blasting agent typically detonates. After the primer is fired, a certain time passes, during which the detonation travels through a distance in the borehole, before the blasting agent reaches this steady state velocity. In this area of the borehole, which can extend from the primer to a distance of several borehole diameters, the detonation wave will travel at a "transient velocity." This transient velocity may be significantly less than its steady state velocity, and will represent a loss of energy.

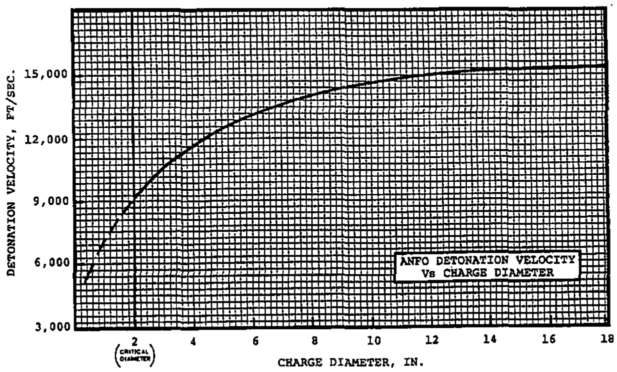


Figure 1.

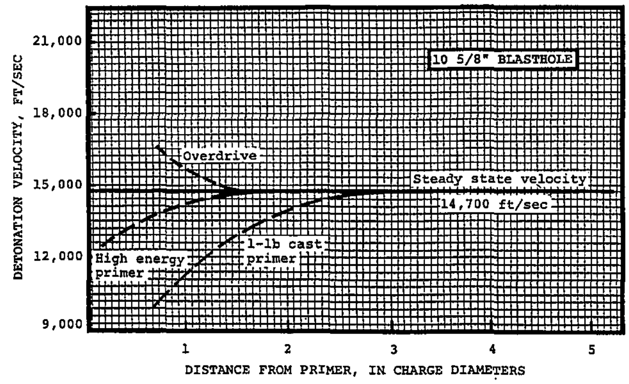


Figure 2.

While the final steady state velocity is not affected by the primer, the time and distance required to reach it depends on the primer and the priming procedure. **Figure 2** is a chart of detonation velocity versus distance from the primer for three different types of primers.

Line 1 represents a 1 pound cast primer in a ten inch diameter borehole, which produces steady state velocity in 3 charge diameters, or approximately 30 inches. In deep boreholes with a long powder column, such priming would probably be satisfactory unless the toe was very difficult to pull. However, in shallow boreholes, or boreholes loaded with a relatively short powder column, this 30 inch region of lower velocity may represent a significant loss of energy. For example, in a 20 foot powder column, nearly 12. 5 % of the powder is detonating below steady state velocity.

Line 2 represents a high energy primer, such as a combination of a cast primer imbedded in several feet of water gel in the borehole. This will cause the ANFO column to reach steady state of velocity in approximately one charge diameter or 10 inches. This method is generally accepted as the most effective method to prime ANFO in order to release the maximum amount of useful energy.

Line 3 shows a condition known as overdrive, which normally does not occur in actual field blasting. However, test shots, with extremely high energy primers, have shown these results. The ANFO detonates at a higher velocity for a brief time before decreasing to its steady state velocity. This curve is illustrated to disprove the notion that the use of an extremely energetic primer could cause the ultimate steady state detonation velocity of ANFO to be increased.

Any discussion of ANFO as a blasting agent must note its one major drawback, that is, its lack of water resistance. If ANFO is exposed to water in the borehole for any length of time, it will show a decrease in detonation velocity. The greater the amount of water, the ANFO is subjected to, and the longer the time of exposure, the worse the performance of the explosive becomes. Tests have shown that a water content of 10% can result in detonation failure, even after only a few minutes exposure. It is essential that either the ANFO be used only in dry conditions, or steps be taken to keep the blasting agent dry. These can include dewatering of the boreholes, or using plastic borehole liners.

One physical property, that is sometimes considered as a disadvantage to ANFO, is its density. It has a relatively low density or specific gravity, typically from 0.82 g/cc to .88 g/cc. Low density of an explosive means that it will have a low "loading factor", which is the pounds of explosives that can be loaded per foot of borehole. In operations where the blaster desires to maximize the explosive charge in the powder column, a low loading factor does create a problem.

However, in other cases, blasters may wish to get more widespread distribution of the explosive throughout the borehole and the blast pattern. A low density explosive often times, will accommodate this much better than a high density one. Therefore, the density and loading factor of ANFO may be either an advantage or disadvantage, depending upon the specific blast design. It is one of the basic characteristics of an explosive that the blaster must consider when selecting which explosive to use. It may also determine the number and size of the boreholes that need to be drilled and loaded.

Finally, there are several other points to consider when priming ANFO, such as:

1. The detonation pressure of the high explosive, used as a primer, is as important as its detonation velocity when determining in its effectiveness as a primer. At least one explosive manufacturer recommends a primer with a detonation pressure of at least 80 kilobars.
2. The diameter of a primer should approximately match the borehole diameter so that it produces a stable, flat pressure wave entering into the ANFO.
3. Multiple primers may be needed in very deep boreholes, especially in holes where the geology or burden dimension may cause rock movement that could vent the borehole pressure before the powder column completely detonates. Multiple primers may also be appropriate in boreholes with multiple zones of difficult breakage. It is generally accepted practice that the primer should be placed in the area of most difficult breakage.
4. Care must be taken when using large detonating cord downlines in small boreholes with ANFO. This may have a detrimental effect on the ANFO by desensitizing it or even causing low order detonation.

Over the past forty years, ANFO has retained its leading position in the explosive market, in spite of the introduction of many newer products and blasting techniques. And it is very likely that ANFO will continue for the foreseeable future to remain the standard, against which all performance versus cost considerations will be compared.

ISEE - Journal of Explosives Engineering-
Vol. 14 No. 4 July/August 1997
Back to Basics: TheClassification and Properties of Explosives

BACK TO THE BASICS

by Larry Schneider

The Classification and Properties of Explosives

A fundamental responsibility of blasters, often defined in regulations as well as assigned to him by their employer, is to choose which type of explosive to use on a particular job. In order to make an informed choice, they must be familiar with more than just the brand name on the explosive, they must also recognize the various classes of and types of explosives, and their characteristics. The chart on page 29 illustrates an overall summary of the classification of explosives, and contains a very brief description of each type based upon its composition and properties.

At the top left hand side of the chart, low explosives are separated from all other types of explosives by the fact that a low explosive does not generate a shock wave when initiated. The reaction in a low explosive, such as black powder, is properly called a deflagration, which is a rapid burning that produces large quantities of gases. A detonation, on the other hand, produces a large amount of high temperature and high pressure gases, but also is accompanied by a shock wave. The existence of this shock wave is the primary distinguishing characteristic between high and low explosives.

On the top right side of the chart, High Explosives and Blasting Agents are separate classes of explosives. The difference between these is their dissimilar sensitivity to a blasting cap. A blasting agent will not initiate when placed in contact with a detonator (blasting cap) and the detonator is fired. Blasting agents require more energy to initiate, normally a primer cartridge of high explosive must be detonated in contact with the blasting agent. To initiate a high explosive, requires only a detonator fired in contact with it.

The decreased sensitivity of a blasting agent offers several obvious safety advantages when blasting agents are being transported, stored, and/or handled. Indeed, a number of regulatory agencies recognize that the stability of blasting agents require less stringent standards for the storage and transportation of blasting agents as compared to those for high explosives.

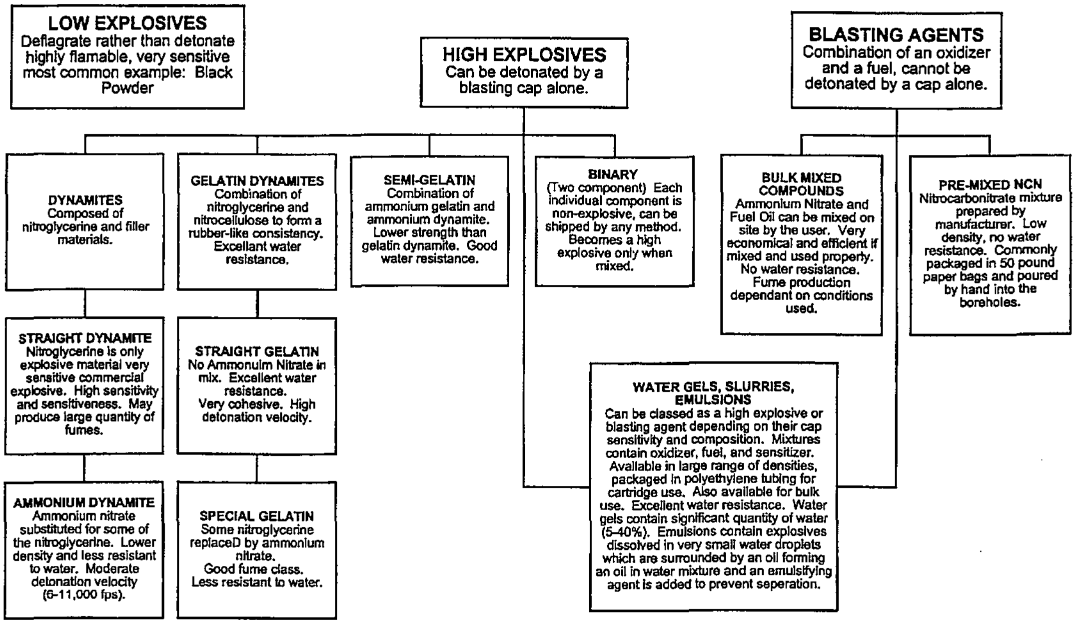
When selecting an explosive to be used on a particular job, the blaster must know the conditions that he will be working under, and must choose a type of explosives which are most appropriate for those circumstances. Economic considerations will always enter into the selection of materials, including explosives, to be used on any project. However, the blaster must insist on explosives of a type that is compatible with the job conditions and equipment he is using.

Cost should never take priority over proper application of explosives, particularly when safety may be affected. It is also important to note that the price of the explosives is only one factor to consider in evaluating the cost of blasting. Inexpensive explosives that do not serve the purpose for which they are intended are no bargain. High energy explosives may have a higher initial price, but savings in drilling, loading, and mucking the rock may offset this cost. A thorough study of the overall costs involved in a blasting program is essential before a judgement can be made on the economic benefits of any particular explosive.

To ensure that he selects the proper explosive, the blaster must have a basic understanding of the properties and characteristics of explosives. These are:

1. Density
2. Water Resistance
3. Detonation Velocity

DESCRIPTIVE CLASSIFICATION OF EXPLOSIVES



4. Strength
5. Fume Characteristic
6. Sensitivity
7. Sensitiveness

When loading a borehole, the **density** of the explosive will determine how many pounds of explosives can be loaded into a certain size borehole. A dense explosive is one which is concentrated and will enable the blaster to load more explosives per foot of borehole than a low density one. ANFO, the most common explosive used, has a relatively low density. However, it is possible to blend ANFO and emulsions in a bulk truck, which gives the blaster the ability to increase the density of the blasting agent, or even vary the density loaded within a single borehole.

When loading in boreholes containing water, it is important to use an explosive with a density greater than the density of water. If not, the explosive will float, and the charge column can become separated, resulting in a misfire. Density is measured in terms of specific gravity, which is the ratio of the mass or weight of a material (an explosive in this case) to the mass or weight of an equal volume of water. Materials with specific gravities less than 1.00 are lighter than water; materials with specific gravities greater that 1.00 are heavier than water. Therefore, an explosive used in a water-filled borehole should have a specific gravity greater than 1.00.

The **water resistance** of an explosive is also an important property to be considered in such a case. It is a measure of how much exposure to water, an explosive can withstand before becoming desensitized or at least before losing some effectiveness. This property is generally specified in qualitative terms such as good, fair, poor, etc. Emulsions, slurries, gelatins, and high density explosives are said to have "good to excellent" water resistance. Low density, porous explosives, such as ammonia dynamites usually have poor water resistance. ANFO loaded in bulk has extremely poor water resistance.

The **detonation velocity** of an explosive is considered by many blasters to be a very important indicator of the rock-fragmenting ability of an explosive. Detonation velocity is the actual speed with which the detonation wave travels through a powder column. It is measured in terms of feet per second or meters per second; with ranges of 5,000 - 6,000 ft/sec for slow velocities, up to 24,000 ft/sec for very high velocity explosives. When detonated, high velocity explosives expend a greater percentage of their energy in the creation of a shock wave. This shock wave provides more shattering effect on the rock, which is especially useful in hard, massive rock formations. Explosives with lower velocities concentrate more of their energy in the formation of gas pressure, which create a heaving or lifting action on the rock. This type of explosive has the best results when used in softer rock or that which has thin seams or layers.

The **strength** of an explosive can be expressed and measured in several ways, one of which is by listing a percentage. Years ago, 60% straight dynamite actually meant that the dynamite was composed of 60 % nitroglycerine and 40% other materials. However as the chemistry of explosives advanced, other ingredients were substituted for, or combined with nitroglycerine to provide the same amount of energy. Today, the percentage listed on the cartridge or case does not reflect the actual amount of nitroglycerine in the explosive but is used for comparison only. For instance, a cartridged explosives listed as "40% gelatin" does not contain 40% nitroglycerine, but it is considered to have a strength equal to a straight dynamite that would have contained 40% nitroglycerine. Care must be taken because the percentage ratings are not linear. That is, 60% gelatin is not 1 1/2 times stronger than 40% gelatin.

Today, manufacturers of explosives precisely measure and report the actual energy of their explosives in terms of calories per gram, foot-lb per pound, or other units of energy per quantity of explosive. A switch to a higher strength explosive, should provide a blaster with better fragmentation without a change in pattern, or enable him to expand his blasting pattern with no loss of efficiency. It is the explosive energy, designated as strength, that is doing the work of breaking and moving the rock.

A blast produces large quantities of gases, some innocuous, such as carbon dioxide, carbon monoxide, and steam; but also some that are very toxic, such as the oxides of nitrogen. The **fume charac-**

teristics of an explosive is a measure of the quantity of poisonous fumes produced by detonation. Such fumes can be very hazardous even in small concentrations. When blasting on the surface, the fumes are usually dispersed rapidly by the air. However in a confined area, such as a tunnel, it is important to use an explosive which produces a minimum amount of toxic gases, in addition to providing adequate ventilation. The Institute of Makers of Explosives and the U. S. Bureau of Mines both have methods of classifying explosives according to the amount of toxic fumes they produce when detonated.

The conditions under which an explosive is detonated will also effect the quantity of fumes it produces. For example, ANFO, when mixed in proper proportions, well confined, and detonated in a dry borehole produces a minimum amount of fumes. However, if detonated when poorly confined, when wet, or with an unbalanced mixture of fuel oil, ANFO can produce large quantities of oxides of nitrogen.

The **sensitivity** of a high explosive must be such that it will be reliably initiated by a detonator, yet it cannot be so sensitive to shock, heat, or friction that becomes unsafe to handle. The sensitivity of a blasting agent will depend upon its composition, which will determine what type of primer must be used to initiate it.

Sensitiveness is the ability of an explosive to propagate continuously once it has been initiated, that is, the detonation will not die out in the powder column. Explosives with high sensitiveness, may detonate when the shock wave from an adjacent hole reaches them. This hole-to-hole propagation will most likely occur when very sensitive high explosives are used in boreholes drilled very close together or in wet conditions. Such propagation can be a serious problem because it disturbs the delay pattern planned for the shot, and can result in excessive flyrock or high vibration levels.

To evaluate which explosive is best in any situation, the blaster must rely on information from the explosive manufacturers, and often on their advice in order to make the right choice. However, he must understand the criteria to use for choosing explosives and recognize when any change in field conditions necessitates a change in explosives' properties.

ISEE - Journal of Explosives Engineering-
Vol. 14 No. 3 May/June 1997
Back to Basics: Basic Blasting Mathematics

BACK TO THE BASICS

by Larry Schneider

Basic Blasting Mathematics

Some blasters will strenuously argue that blasting is an art, one which can be mastered only after years of experience, and then only by certain select, and talented individuals. These "artists" are able to "read" the rock, and intuitively design a pattern that will break it effectively. I would contend that blasting is very much a science, or engineering discipline. The results of a blast can be accurately predicted and controlled provided the blaster accounts for all the variables that determine the outcome of a shot. Unfortunately, there are a very large number of factors that must be considered, some of which are difficult to measure and some of which may be completely hidden from the blaster. For example, it is not always possible to detect potential geological problems, such as mud seams, caverns or voids, unless the boreholes happen to be drilled so that they intersect these areas. Even in cases where a borehole intersects a mud seam or void, unless the driller is particularly vigilant, he may not be able to provide much information to the blaster.

Assuming that a blaster can obtain all the data that he needs to design a safe and efficient blast, there will necessarily be some basic mathematics that he or she must be able to do. The most fundamental calculations that a blaster must be able to do involve the distribution of explosives throughout the rock mass. These are the calculations of: 1) volume of rock broken, 2) powder factor, and 3) loading factor.

Determining the Volume of Rock Broken

Before anything else in a blast plan is considered, the blaster must determine how much rock must be broken by the shot, and how much will be broken by each borehole. The volume of rock to be fragmented is determined by the geometry of the blast pattern. The layout of the blast can be very simple, such as a single row breaking to an open face as shown in **Figure 1**.

In the diagram the solid line would indicate the existing face of rock before the shot is detonated. The dashed line indicates where the rock face will be after detonation. The area between the two lines represents the fragmented rock. To calculate the volume of the broken rock, multiply the area times the height of the rock or use the formula for volume of a rectangular solid which is:

Volume = Length X Width X Height

In this case, length is the length of the shot, the width is equal to the burden (the distance from the borehole to the original free face), and the height is the depth of the rock. Subdrilling is not considered in this calculation. The height of the rock mass to be broken is the depth of the borehole minus any subdrilling, which should correspond to bench height.

Often trench blasting involves drilling through the dirt and loose material overlaying the rock, and then through the rock to grade. When boreholes are drilled through this unconsolidated "overburden" to the rock, the depth of this "overburden" is not included in the height of the rock.

In a more complicated or irregular shot pattern such as in **Figure 2**, it is not as easy to calculate the total volume of the rock broken. Rather, the method for finding rock broken in such a blast is to calculate the volume broken by a single borehole, and multiply by the number of holes. This can be used in both simple and complex patterns and will give good approximations of the rock produced by a blast.

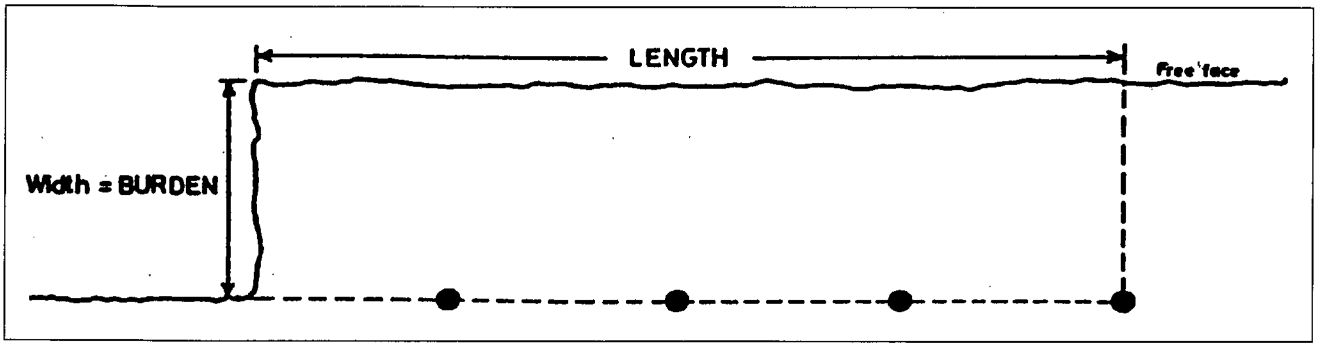


Figure 1

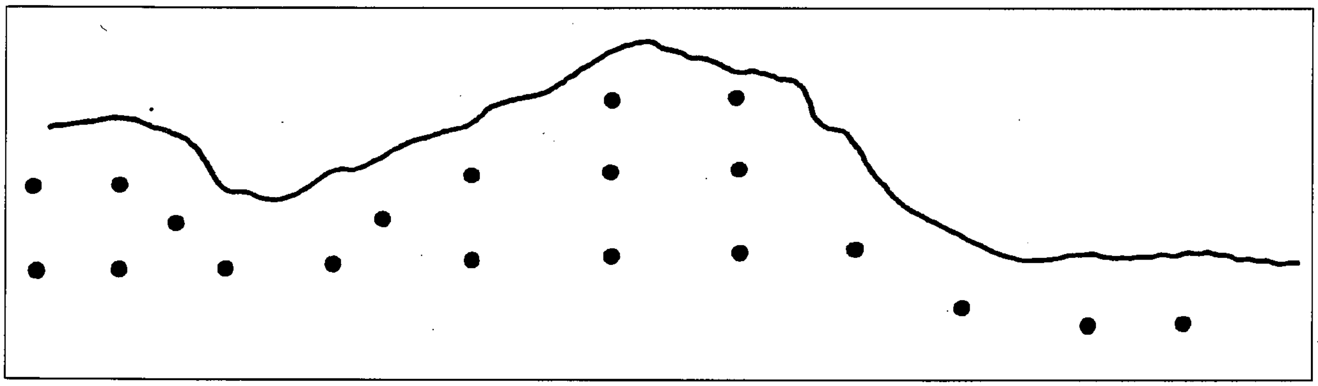


Figure 2

Assuming the burden, spacing, and depth are measured in feet, the volume of rock in cubic yards is given by the following formula:

$$\text{Volume (yd}^3\text{)} = \frac{\textbf{Burden (ft) X Spacing (ft) X Depth (ft)}}{27}$$

The 27 in the denominator is a conversion factor to change cubic feet to cubic yards, (1 yd^3 = 27 ft.^{3}).

Example 1: A borehole is drilled on a 10' X 12' pattern 30 feet deep. How many cubic yards of material will this hole break?

$$\text{Volume} = \frac{\text{Burden X Spacing X Depth}}{27}$$

$$\text{Volume} = \frac{10' \text{ X } 12' \text{ X } 30'}{27} = \frac{3600}{27}$$

Volume = 133.3 yd^3

Example 2: A blast consists of 80 holes drilled on a square 10' X 10' pattern. The depth of the borehole is 30 feet; the subdrilling is 3 feet. How many cubic yards of material will be broken by this blast?

Solution:

$$\text{Volume} = \frac{10 \text{ X } 10 \text{ X } 27}{27} = 100 \text{ yd}^3$$

Total volume of shot = # of holes X volume per borehole

Total volume of shot = 80 X 100

Total volume of shot = 8000 yd^3

Calculating Powder Factor

Powder factor is defined as a ratio of the quantity of explosives needed to break a quantity of rock. By this definition powder factor could be expressed as pounds of explosives per ton of rock (lb/ton), pounds of explosive per cubic yard of rock (lb/yd^3), or in any other units of measure that would specify explosives and rock amounts. Pounds of explosives per cubic yard of rock is a widely accepted form of expressing the powder factor, and the one on which the following examples are based.

Powder factors vary for different blasting operations depending on how hard the rock is, the density and strength of the explosive used, the blast pattern, the geology, the degree of fragmentation required as well as a host of other factors.

On large scale operations such as quarries, mines, and highway excavation, powder factors may vary from 0.5 lb/yd^3 to 2.0 lb/yd^3. For smaller operations, powder factors may range from 1.0 lb/yd^3 for wide trenches and easy shooting to 8.0 lb/yd^3 for narrow trenches and hard shooting.

The usual way of calculating powder factor is to find the cubic yards of rock a borehole will break and divide this into the pounds of explosive loaded in that borehole:

$$\text{Powder Factor (lb/yd3)} = \frac{\text{amount of explosive (lb)}}{\text{volume of rock broken (yd}^3\text{)}}$$

Powder factor can also be used as a method of blast design or at least as a way of determining the amount of explosives to be used in a borehole. The formula above can be rewritten as :

Pounds of Explosives = Powder Factor X Volume of Rock Broken

This assumes that the blaster has experience and/or knowledge about the type of rock to be blasted, the method of blasting, and the correct powder factor to be used.

Example 3: A borehole will break 100 yd^3 of material. If 130 pounds of explosives are loaded into the hole, what is the powder factor?

Solution:

$$\text{Powder Factor} = \frac{130 \text{ lb}}{100 \text{ yd}^3} = 1.3 \text{ lb/yd}^3$$

Example 4: A blast is drilled on a 12' X 15' pattern, 40 feet deep. Each hole contains 300 pounds of explosive. What is the powder factor?

Solution:

$$\text{Volume of rock broken} = \frac{\text{burden x spacing x depth}}{27}$$

$$\text{Volume of rock broken} = \frac{12 \text{ X } 15 \text{ X } 40}{27} = \frac{7200}{27}$$

$$\text{Volume of rock broken} = 266.67 \text{ yd}^3$$

$$\text{Powder Factor} = \frac{\text{pounds of explosive}}{\text{cubic yards of rock}}$$

$$\text{Powder Factor} = \frac{300 \text{ lb}}{266.67 \text{ yd}^3}$$

$$\text{Powder Factor} = 1.125 \text{ lb/yd3}$$

Example 5: A blaster has drilled a pattern of 18 ft by 21 ft and 60 feet deep. He wants to use a powder factor of 1.20 lb/yd^3, how much explosives must he put in each borehole?

Solution:

$$\text{Volume of rock to be broken} = \frac{\text{burden x spacing x depth}}{27}$$

$$\text{Volume of rock to be broken} = \frac{18 \text{ x } 21 \text{ x } 60}{27}$$

$$\text{Volume of rock to be broken} = 840 \text{ yd}^3$$

Pounds of explosives = powder factor x yd^3 of Rock to be broken

Pounds of explosives = 1.2 x 840 = 1008 lb/hole

For this blast design to be practical, the borehole must be of sufficiently large diameter in order to hold 1008 pounds of explosives and still have space for an adequate amount of stemming. Obviously, a blaster designing a pattern with a relatively large burden and spacing such as above, must have a large diameter drill.

Loading Factor

The loading factor for a borehole is defined as the weight of explosives loaded per foot of borehole. The actual value of the loading factor is dependant on the diameter of the explosive column and the specific gravity of the explosive loaded into that borehole.

When using a free flowing or bulk explosive such as ANFO or emulsion, the diameter of the explosive column will match the borehole diameter. A rigid cartridge will normally have a diameter smaller than the borehole diameter.

The numerical values for loading factors are readily available on charts with hole diameter and specific gravity as the two variables, and listing the pounds of explosives per foot of borehole for every combination of those variables. The table to the right is a small part of a typical chart. To find, for example, the loading factor for a 5-inch diameter explosive column using an explosive with a specific gravity of 1.00, read down the left hand column to 5 and under the top row to 1.00. Where the row for 5 inch diameter intersects with the column for 1.00 specific gravity, the loading factor of 8.50 pounds per foot will be found.

To compute the total amount of explosives in the borehole, the loading factor is multiplied by the height of the explosive column. The explosive column corresponds to the borehole depth minus the stemming length. Subdrilling is included in the explosive column since subdrilling is loaded with explosives.

Example 6: A borehole is 30 feet deep, and 6 inches in diameter. Stemming is held to 7 feet. Using ANFO with a specific gravity of 0.8, how many pounds of explosive are loaded into this hole?

From the table, the loading factor is 9.81 lb/ft

The height of the explosive column = 30 feet - 7 feet = 23 feet

Borehole	Specific Gravity of Explosive						
Diameter (in)	0.80	0.90	1.00	1.10	1.20	1.30	1.40
3.5	3.33	3.75	4.16	4.58	5.00	5.42	5.83
4.5	5.51	6.19	6.88	7.57	8.26	8.95	9.63
5	6.81	7.65	8.50	9.35	10.20	11.05	11.90
6	9.81	11.01	12.24	13.46	14.68	15.91	17.13

Pounds of explosive = height of explosive column X loading factor

Pounds of explosive = 23 feet X 9.81 lb/ft

Pounds of explosive = 225.6 lb

Example 7: A 4 inch diameter hole is loaded with 3.5 inch rigid cartridges of explosive having a specific gravity of 1.3. If the explosive column is 12 feet high, how many pounds are loaded into the hole?

Solution:

Loading factor is 5.42 lb/ft

Pounds of explosive = 12 ft X 5.42 lb/ft = 65.04 lb

Neda Mine Bat Habitat *(continued from page 12)*

been successful, a clean cut of the mark with virtually no damage beyond. The ore car was retrieved with no damage, much to the delight of the local historical society.

Final Installation

A total of ninety-six feet of five foot diameter galvanized culvert was installed in the cut, extending both into the adit and out of the face. Wooden shoring was put in place to enhance the strength of the culvert during the inevitable settling that would occur. Backfilling was completed and a riprap surface finished with on site material. Fifteen other areas were filed and covered with site generated riprap to prevent entry to the works. This was vital not only for the protection of the bats, but to end the intrusions of local adventurers and the legal liabilities inherent. A tube steel gate was built in my shop that would prevent unauthorized access by humans yet allow the bats to freely pass. At the request of the site manager, Dr. Reinartz of UWM, the as drawn design of the gate was changed to allow for a larger entry in case the need for a stretcher removal of an injured person was required. Once installed the mine was closed. The total time to completed installation of the tube was nine days, well under schedule requirements.

The mine now has had extensive monitoring equipment installed for airflow, temperature and population densities. This is now one of the two largest known colonies of bats of this type. The installation will serve far into the future both as habitat and study information for generations.

For further information, please contact Robert Eder at (608) 634-2702 or Bat Conservation International at (512) 327-9721.

ISEE - Journal of Explosives Engineering-
Vol. 13 No. 9 November/December 1996
Back to Basics: Flyrock Part 1: Safety and Causes

BACK TO THE BASICS

by Larry Schneider

Flyrock (Part 1: Safety and Causes)

Everyone in the blasting industry knows what is meant by flyrock, but there are several perspectives or ways to view flyrock. In some cases, flyrock has simply been described as ANY rock thrown in the air by a blast. Using this definition, even rock that rose only three feet off the ground, could technically be considered flyrock. Obviously, such flyrock is not the kind a blaster needs to be concerned with.

In certain other texts, flyrock is defined as "any dirt, mud, stone, fragmented rock or other material that is displaced from the blast site by being thrown in the air or cast along the ground." Several points to note about this definition are:

1. Flyrock can be mud or dirt, it does not necessarily mean only rock or stone.
2. The material can be displaced from the blast site by traveling along the ground as well as through the air. That is, flyrock doesn't necessarily have to fly.

If you also examine this definition of flyrock, it says nothing about flyrock being dangerous. Therefore, cast blasting could fit this definition since the material is displaced from the blast site by the force of the detonation. However, even if cast blasting may meet this definition, it is not the nightmare referred to earlier, because it is both expected and controlled. When done correctly, cast blasting is a positive outcome of the blast design. However, the flyrock that the blaster must be concerned about is neither controlled nor planned, and would normally be considered as excessive.

When the blaster is concerned with flyrock and safety, there are two possible problems: either the amount of material thrown, or the distance the material travels is excessive. When either or both of these things exceed what most experienced blasters would reasonably expect from a blast, there may be serious problems.

Some laws are written to specify what is considered to be excessive distance for flyrock. They may say that "flying rocks shall not be allowed to fall greater than one-half the distance between the blast and a dwelling house, public building, school, church, commercial or institutional building." This is a quantitative way of evaluating the degree of flyrock, which has the advantage of flexibility in that it does not set a specific distance and apply it to all blasting operations.

It would simply not be feasible to set a particular distance as the limit for flyrock for every case. For instance, if 300 feet was chosen as a universal limit on flyrock, it obviously would not be appropriate when blasting in the midst of a residential area. However, when blasting on a mine site in an isolated area which may be three miles from your nearest neighbor, 300 feet is unnecessarily restrictive. The disadvantage to this type of law is that it does mean that flyrock can remain within the boundaries of a job site or mine permit and still be in violation.

In most jurisdictions, there will be laws and regulations that restrict flyrock in the vicinity of highways, waterways, that endanger property or constitute a hazard to employees or the public. Many of these laws are more directly concerned with securing the area around a blast site.

Provided a blaster does a good job of clearing and securing the area, even if a blast generates a larger amount of flyrock than usual, it should have no effect. If the blaster is lax in clearing the area or blocking access, even a well controlled shot can result in enough flyrock to injure or kill someone. In fact a U. S. Bureau of Mines study done in the late 1980's, showed that the two leading causes of fatalities in blasting operations are :

1) Failure to secure the area
2) Excessive Flyrock.

Therefore, in a discussion of flyrock and safety, there should be some consideration given to securing the area.

Immediately before detonation, the blaster's most critical concern must be that the area is completely clear and access to the site is controlled. He should have a pre-determined plan for safeguarding all personnel and the public. This is a matter about which the blaster can make no assumptions, he must be absolutely sure that the area is clear. Flyrock has been known to travel remarkable distances from a blast, and a plan to protect against flyrock must take into account the worst case scenario. Furthermore, when blasting in a public area, the blaster must realize that the public is both curious and uninformed about the use of explosives. They will sometimes place themselves in dangerous situations in an attempt to see what is happening. In the surface coal mines of Appalachia, there have been a number close calls where people who ride "four-wheelers" in these isolated areas, drive directly up on a blast site. There are also reported instances of hunters or back-packers walking in wooded areas near blast sites and who deliberately remain nearby in attempt to watch a blast being set off.

All roads leading into the vicinity of the blast area must be physically guarded, and all personnel and equipment must be removed from the area to a location which is both at a safe distance and well-protected. A thorough visual inspection of all possible areas that could be affected is essential prior to sounding the warning signals. It is imperative that control of access to the site be maintained continuously; if such control is lost or removed for even a few seconds, a repeated inspection of the area is mandatory to be sure no one has entered the area during the time that access control was lost.

The need for protection from flyrock is most serious for the blaster himself, since he is usually the person closest to the detonation. Even though most blasters want to fire the blast from a position with a clear vantage point to see the entire blast area and the blast itself, it is imperative that they take adequate precautions to protect themselves. This means that the blaster must be at a safe location, and under substantial cover. Light buildings, pickup trucks, and other vehicles which are often used as cover, have also often been penetrated by flyrock. The use of specially designed blast shelters are becoming more widely available and used, and represent a step forward in providing for the safety of the blaster.

A safe location and sufficient cover is critical to the blaster's protection because lead lines or the shock tube is seldom long enough to allow the blaster to be beyond flyrock range. Another critical point is that no one, including the blaster, should ever be located in front of the shot. Since so many injuries are caused by flyrock, any discussion of safety should emphasize the means to prevent it. Some of the common causes of flyrock are as follows:

1) Excessive amount of explosives used.
2) Inadequate Burden.
3) Explosives loaded into voids, crevices, mud seams, or any incompetent material.
4) Spacing and burden exceed the depth of the borehole.
5) Inadequate amount or type of stemming.
6) Lift shots or shots which are over-confined.
7) Poor delay timing in the pattern or detonators firing out of sequence.

From this list, it should be obvious that the best precaution against flyrock is a good blast pattern, one which effectively distributes the explosive energy into the rock so that the energy is nearly all used to fragment the rock, and whatever energy is left over displaces the rock in a controlled manner. A poor blast design can result in a blast which the explosive is under-confined, that is, the strata of rock is not strong enough to contain the force of the detonation.

ISEE - Journal of Explosives Engineering-
Vol. 14 No. 1 January/February 1997
Back to Basics: Flyrock Part 2:
Prevention

BACK TO THE BASICS

by Larry Schneider

Flyrock (Part 2: Prevention

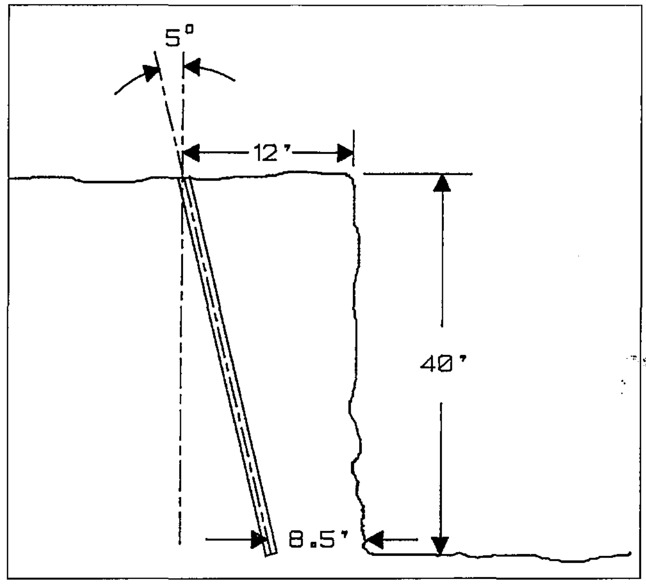


Figure 1

In part one of this series on flyrock seven common causes of flyrock were listed. The first cause was described as an excessive amount of explosives. When you hear that description, the implication is that the blaster loaded "TOO MUCH EXPLOSIVES IN THE HOLE." In fact, this is what the public often accuses blasters of, whenever they have a complaint about the ground vibration, noise or flyrock; that is, the blaster deliberately put too much powder in the hole. As the blasters themselves are well aware, that explanation is too simplistic because there is only a certain amount of explosives that will fit into a borehole of a particular diameter and depth. Furthermore, due to the economics of blasting, the idea is certainly not to use any more explosives than necessary.

So the statement that there was an excessive charge in a blast usually means that there may be some other problems, such as the blast was loaded with a powder factor (as measured in lb of explosives per yard^3 of rock) that was too large for the type of rock being shot. A powder factor that is too high can cause enormous movement of the rock. And an excessively large powder factor can actually occur due to any of several of the causes described in the list. For instance, if the burden distance is too small for the borehole diameter, or if not enough stemming is loaded in the borehole, those factors also result in an excessive powder factor and an overloaded blast.

This may result from poor design when planning the burden or spacing. Or sometimes, poor execution in the field occurs when trying to implement a good blast design. For instance, a blaster may load a hole where the powder factor has been calculated correctly for a given burden, spacing and depth, but the boreholes were not drilled accurately according to that design. The blaster must also be aware of what the true burden is on each borehole, and whether or not that burden is consistent through the length of the borehole. Note that the true burden is determined by the delay timing sequence as well as the blast geometry.

If we look at some of the following diagrams, we can see in some cases clearly where the burden turns out to be less than that which the blaster expected. In figure 1, the bench has a good vertical free face, but the drilling was done poorly. If the blaster proceeds to load the borehole for the 12 foot burden he has at the top, he will be overloading the bottom of the hole where he has only 8.5 ft. An inaccuracy such as this, when the drill is off the vertical, will be magnified the deeper the borehole is drilled. As an example, a borehole 40 feet deep, which is drilled 5 degrees from the vertical results in an error of 3.5 feet at the bottom of the hole. The same borehole drilled 100 feet deep with the same 5 degree error, will be off by nearly 9 feet at the bottom of the hole. Even in the first instance, where the burden was off by 3.5 feet, the powder factor may vary by 20% from top to bottom of the borehole.

As an example of this type of error, consider a blaster who intends to drill a 12 x 15 pattern, 40 feet deep, using 8 ft of stemming in a 51/2 inch diameter, and loads it with a loading factor of 8.25 pounds of ANFO per foot. With this pattern, he expects to have an average powder factor of 1.00 lb/yd^3 for the borehole. If, however, the driller errs by 5 degrees from the vertical, his burden at the bottom is only 8.5 ft., and his average burden throughout the borehole would be 10.25 feet. His actual powder factor for the entire hole will be 1.16 lb/yd. Even more striking, is the fact that while the powder factor for the top one foot of the powder column is 1.29, the powder factor at the bottom of the borehole is 1.75 lb/yd, an increase of more than 35%.

Figure 2 shows a perfectly drilled vertical hole on a level bench, but due to the equipment excavating material at the front of the bench, the blaster may encounter a bench with a profile like this. In this example, if the blaster does not check the shape of the free face, he may load the shot for a 15 ft burden and only have 8 feet of rock confining his explosive charge.

A similar instance is where the holes are "buffered" in front of the shot, and the blaster drills near the free face to ensure that he "pulls the toe." The profile may look like the one shown in figure 3. The first row of hole is drilled close to the crest since there is a large buffer that reaches nearly to the top of the bench. Subsequent rows of holes are set back a reasonable distance, and the blaster assumes that the buffer will confine the blast on the outside boreholes. And it may work as planned provided the powder column is not loaded too high, so that the top portion of the charge is not near or above the buffer. If a charge is loaded such that the charge is unconfined in this top portion, it can throw rocks over a long distance.

Accuracy in drilling is extremely important when angled holes are used. The setup distance from the face, the angle of the drill must be measured carefully to ensure that the proper burden exists at the toe. Failure to do so can result in charges that are placed too close to the face with less confinement than intended.

If explosives are loaded into faults, crevices, or mud seams that the borehole passes through, the blaster should expect excessive flyrock. The driller has a crucial role to play in the preparation of the blast. Information about any unusual conditions such as mud seams or voids encountered in the borehole must be recorded or logged, and the blaster must rely on his driller to communicate any unusual conditions of

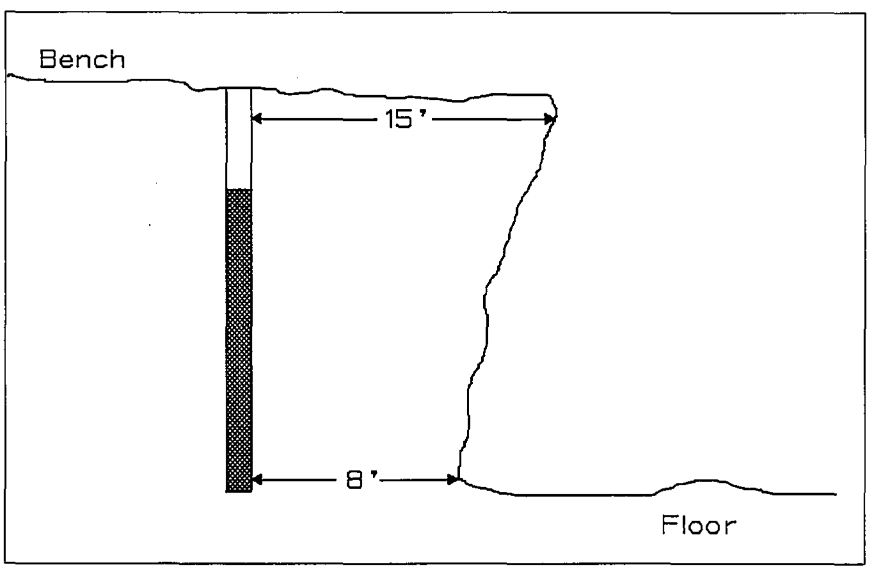


Figure 2

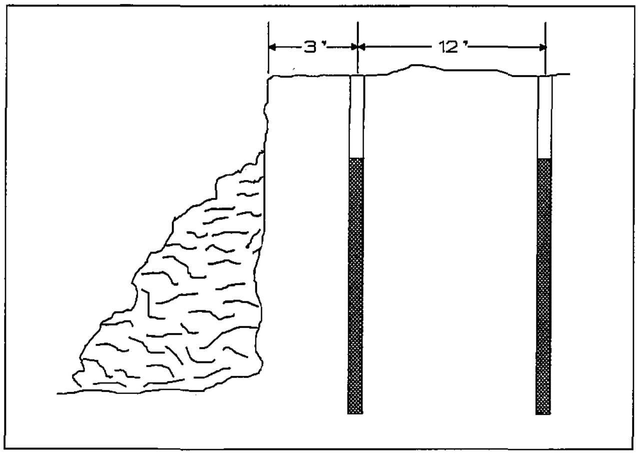


Figure 3

the boreholes he has drilled. The driller must be constantly aware of what is happening as he drills, so he will know if he encounters a significant mud seam or a void such as a cavern or an abandoned underground mine.

If explosives are loaded into a mud seam, the mud does not have sufficient resistance to confine the energy of the detonation. As long as the blaster knows in advance that a mud seam intersects the borehole, he can take steps to eliminate the danger. This is normally done by stemming through the mud with inert material to make two separate charges in the borehole. A cardinal rule for a blaster is that explosives should never be loaded into anything except competent rock.

Likewise, if a borehole is drilled so that it cuts into a cavern or underground mine, the blaster may load huge amounts of explosives, and if detonated will create a violent result. If the blaster is careless while loading the borehole, especially when using bulk explosives, he may not detect the fact that a large amount of explosives are going into the borehole. It is always important that a blaster constantly monitors the rise of the powder column in the borehole using a tape or other method.

Adequate stemming is required to confine the high pressure gases released by the detonation of the explosive charge. This stemming must be sufficient to prevent the force of these gases from violently cratering to the surface. The explosive force will always be in the direction of least resistance, which should be the burden distance to the free face at the instant of detonation. However, if the stemming length is too small, the most direct path for the gas pressure to vent may be to the surface. In minor occurrences, this results in stemming material being launched away from the blast. More serious cases occur when material around the collar of the borehole can be thrown significant distances.

Adequate stemming does not only mean the length of the stemming, but also the composition of the material used as stemming. Drill cuttings or dust are usually a very poor stemming material, particularly if the borehole is water-filled. Crushed stone of a suitable size so that it interlocks in the borehole is a recommended stemming material on most operations.

Another potential problem occurs if a blast pattern is drilled such that the spacing and burden is greater than the borehole depth. In this situation, the blaster should expect flyrock. Blasters occasionally drill this type of pattern without realizing that they are creating a potential hazard. For example, a blaster using a 6 3/4 inch drill bit tries to blast an excavation to grade that is only 8 feet deep. He may be conscientious enough to realize that he only needs 2 feet of powder in a borehole drilled on a 12 x 14 feet pattern, 8 feet deep to get a proper powder factor. However, such a design produces a burden greater than depth, so that the nearest direction for relief is the surface, and rock may be thrown straight up into the air.

Certain operations use blasting patterns where the burdens are sometimes close to, or slightly greater than the depth. One of these are the "parting shots" in surface coal mines, where the blaster has to break a layer of rock that lies between two coal seams, this strata of rock may be anywhere from 8 to 20 feet thick and the blaster may have to use a large diameter drill with a 12 x 12 pattern. It can result in a great deal of material thrown, but usually such blasts are a large distance from houses, and roads.

Occasionally blasters in quarries are required to shoot "toe shots" where they come back after the main blasts have failed to pull to grade. On these shots, the boreholes may be drilled in an irregular pattern and very shallow. When they are fired, flyrock is a definite possibility. So called "lift shots" or any shots fired to begin an excavation are also prone to generate flyrock. These shots have no free face and are intended to cause the rock to fragment and swell. However, if they are not carefully loaded and controlled, the fragmented rock again is launched upward. On smaller scale blasts, such as those for setting electric utility poles, the use of "burn or cut" holes serve to provide a place for the bro-

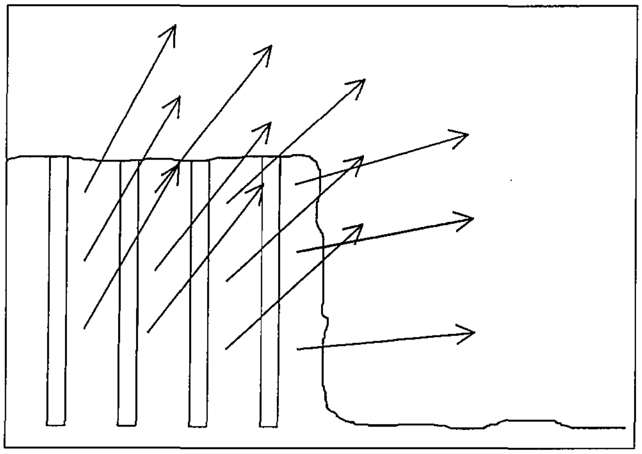


Figure 4

ken rock to move and help control the upward throw. On these shots, blasting mats may be useful, but a good blast design is still critical.

Poor delay timing can generate flyrock. Faulty delay time may be the result of bad design, but could also be caused by inaccurate detonator firing time, or simply human error in laying out the delay detonators. The timing on all shots must allow enough time for the rock to move so the muck does not pile up in front and prevent the intended horizontal movement of subsequent charges. Figure 4 shows the effect that takes place as the detonation proceeds deeper into the bench if there is insufficient time for the rock in front to move. That is, the movement of the rock from each borehole progressively moves upward at an increased angle until the back rows become almost a lift shot and the rock movement is close to vertical. Normally this can be somewhat corrected by providing longer delays between the rows as the shot progresses deeper into the pattern.

Figure 5 shows a delay pattern which illustrates a very simple type of timing delay that results in the same effect. In this case, a mistake has occurred and a #10 delay is misplaced in the shot pattern. When this shot is detonated, the charge in that hole will fire with no relief at all and the only possible movement of the rock around it will be vertical. A blaster would be incompetent if he laid out a shot like that on purpose, and at the very least, careless if he did it by accident. However, with complex timing layouts, both electric and non-electric, any error in the connections can result in holes firing out of sequence. The timing mistake may not be as blatant as the one illustrated to have the same effect.

Regulations usually require that when blasting is done in proximity to buildings and roads where no amount of thrown material can be tolerated, blasting mats or other protective materials should be used to confine any possible flyrock. But even in those cases, the best means of controlling flyrock is still through proper blast design and delay timing. It is therefore extremely important that when a blaster working with a successful blasting program makes any change in the blast design, he must carefully consider any changes from the standpoint of its potential effect on flyrock. While many of the causes of flyrock mentioned previously can be predicted and avoided, it is always possible that there exists some unknown condition that will cause flyrock. For this reason, the blaster must always assume the worst possibility and formulate his plans to clear the area for this case. Regardless of how many "well-behaved" shots he has previously detonated, the next detonation is always the most dangerous.

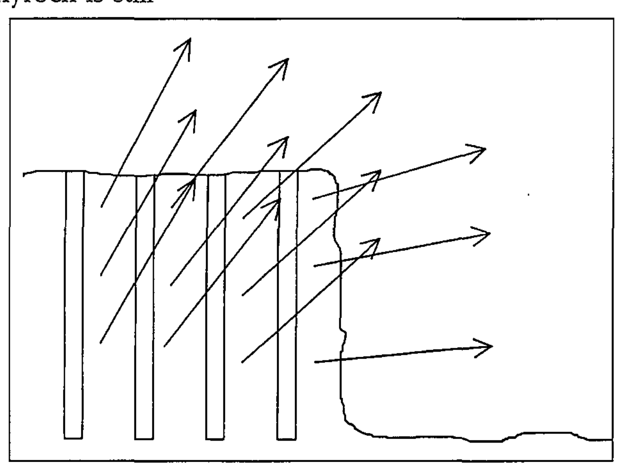


Figure 5

It is the ultimate responsibility of every blaster to oversee the safety and well-being of anyone that could be effected by the blast. They must accept this responsibility and do whatever it takes to protect the public, their co-workers, and themselves.

While the explosive products we use today are the safest, most reliable ever produced, they are only as safe as the individuals using them. Training and education in all aspects of blast safety must always take high priority in our industry, as well as accountability and responsibility in implementing the procedures that are learned.