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Dear Blaster:

The Office of Explosives and Blasting is revising the Self-Study Guide. Section revisions, updates, omissions and replacements cause inconsistency in page numbering.

Except for OEB's Rules, the rules and regulations in this book are subject to change without notice. Current information is available on the following websites: www.wvfiremarshal.org, ww.atf.gov, www.osmre.gov, www.wv.gov.

If you have any questions, please contact our office.

Sincerely,

David Van Linde
Acting Chief

DVL/ja

SELF
STUDY GUIDE

for

WEST VIRGINIA
SURFACE MINE BLASTERS
CERTIFICATION EXAMINATION

1996

Third Edition

Reprinted March 1998

DISCLAIMER NOTICE

ACME Explosives is a fictional company used to keep the study guide as generic as possible. The product values are average numbers for the product they represent and are meant soley for use with this Study Guide. Blasters should consult their supplier to obtain values for the products being used at their operation. Product or trade names used in this Study Guide are those commonly used in the surface mine blasting industry and should not be interpreted as representing an official endorsement of said product or trade names by the West Virginia Division of Environmental Protection.

ACKNOWLEDGEMENTS

The Third Edition of the WV Blasters' Study Guide was written by Donald F. Rapp, Technical Consultant with Explosives Technologies International. It is a comprehensive update of the Second Edition, reflecting advancements in explosive products, initiations systems, and blast procedures, changes in blasting regulations, and a closer parallel to the Certification 8 Hour Training Course Agenda. Both the Training Course and the Certification Examination have been updated as well.

The Second Edition of the Study Guide was written by Dr. Ronald R. Rollins, Professor of Mining Engineering, West Virginia University, in 1986.

The Initial Edition of the Study Guide was published under the direction of Dr. Janet Evans Worthington , Assistant Professor at the West Virginia Institute of Technology circa 1980.

Assistance in editing the Third Edition of the WV Blasters' Study Guide and 8 Hour Training Course was provided by Tony Grbac, Jim Miller, Rick Tankersley, Russell James, John Holliday, Ron Dyer, and Mark Trimble. My personal thanks for all their help.

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HOW TO USE THIS STUDY GUIDE

This study guide was designed as an aid for the surface mine blaster who wishes to take the certification examination. In order to be certified, an individual must apply for certification to the West Virginia Department of Environmental Protection. After making application, the person will be sent a form and a list of steps to be followed. One of these required steps is the successful completion of the Surface Mine Blaster's Certification Examination.

This document is organized to assist the blaster in preparing for the West Virginia Surface Mine Blaster's Certification Examination. Details about the examination and how to prepare for it are covered in Appendix L. Appendix I contains self-study review questions, similar to those found on the examination, which will test the blaster's knowledge and readiness for the exam. While all the information required for the examination is covered in this Study Guide, a review of this guide does not guarantee the blaster a passing grade. Field experience, a workshop or training course, the knowledge of a fellow blaster, and little common sense may provide the needed extra the blaster needs to insure certification.

The document may also be used as a ready reference for the blaster in the field. The generic chapters, (1) Explosives, (2) Initiation Systems, (3) Blast Design, and (5) Environmental Effects, each have a "Blaster's Notes" sheet at the end of the chapter. The blaster should enter on these sheets specific information pertinent his/her operation as it is developed. As an example, the blaster may list the physical properties of the explosives he is currently using at his operation on the sheet at the end of Chapter 1. Although the Study Guide is not a totally complete reference document, it includes selected Federal and State Regulations, a Technical Reference Library, and a complete Glossary of Blasting Terms.

CHAPTER 1

EXPLOSIVES
TYPES & PHYSICAL PROPERTIES

The commercial explosives that we know today have come through a long evloution of development. Although the first documented explosives were developed in the fifth century A.D., the real foundation for the modern day high-explosive industry did not occur until the nineteenth century with the invention of Nitroglycerin. First used as a liquid and later incorporated into dynamite, blasting gelatins, and smokeless powder, Nitroglycerin based products were the core of the commercial explosives market well into the twentieth century. During the first half of the century, the need for improved explosives for the war effort also saw the development of lead azide, PETN, and TNT. In the late 1940's came the most revolutionary development ever to take place in the commercial explosive market, the introduction of ammonium nitrate blasting agents. As diesel fuel oil replaced the other tried fuels such as coal dust, ANFO became universally accepted as the standard of the industry. With safety, cost, and handling advantages, the blasting agent industry began replacing many of the traditional dynamite markets. This refocus resulted in the development of the water gels, slurries, emulsions and other ammonium nitrate based products used today.

In the beginning, as now, the chemical materials in explosives were designed to react rapidly when initiated by a suitable energy stimulus. There may be a single compound or mixtures of chemical compounds, consisting primarily of fuels and oxidizers, creating the explosive material. Although aluminum, iron, sodium, silica, and some other elements may be found in explosives, the primary reaction elements are C (carbon), H (hydrogen), N (nitrogen), and 0 (oxygen). When they react properly and completely, they form the reaction products $C0_2$ (carbon dioxide), H_2O (water), and N_2 (nitrogen gas). This rapid chemical reaction is called a detonation, if the reaction velocity through the explosive material exceeds the sonic velocity (speed of sound) in the material. If the reaction velocity is subsonic (less than the speed of sound), the reaction is called a deflagration. In either case the reaction produces large volumes of high temperature, high pressure gasses. The proper utilization of this energy in the fragmentation, displacement, and shearing of rock, is the art known as blasting.

Blasting is influenced by many factors such as proper bench design, delay timing and charge weight. These factors will be covered in subsequent chapters of this study guide. In addition to these factors, one very important factor, often overlooked, is the type of explosive used and its proper application. There are many important physical properties to consider in choosing the right explosive for the job. This chapter will address what an explosive is and how it functions, explosive physical properties to be considered and the various types of commercial explosives .

WHAT IS AN EXPLOSIVE?

As expressed above, an explosive is a mixture of oxidizers and fuels which when initiated by a suitable energy stimulus (Figure 1.1), produces a very rapid chemical reaction resulting in high temperature and high pressure gasses. When properly confined and initiated, this enormous energy source can be used to do work.

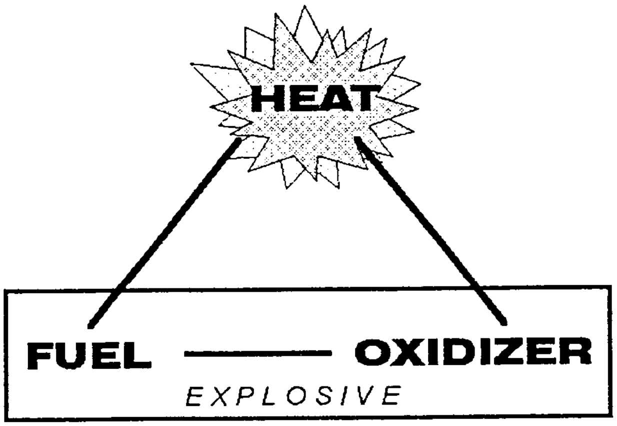


Figure 1.1.

An explosive's ability to do work is dependent on the ingredients used in its manufacture and the conditions imposed by the surrounding media. Ingredients play a key role in the performance of an explosive. The type of ingredient, its heat of formation (heat available for release), the particle size, sensitivity, and other traits will determine the density, velocity, and energy available from the explosive. Conditions surrounding the explosive such as degree of confinement, the type of rock media, presence of water, temperature and pressure will also determine its performance. Figure 1.2 illustrates the phases of a detonation. At the right is undetonated explosive. Passing along and consuming the undetonated explosive is the primary reaction zone. This zone is comprised of a Detonation Front on its leading edge and the Chapmen-Jourquet (C-J) Plane at its rear. Degree of confinement and column diameter will both effect the primary reaction zone and thus the explosive velocity. As the detonation moves through the explosive it produces a shock/stress wave in the surrounding media and expanding gasses. The shock/stress wave, known as the brisance energy, is a function of the explosive's velocity. It is the energy that conditions and creates the initial fractures in the rock media. The expanding gases, known as the work energy, provide the final fragmentation and displacement. This is a greatly oversimplified explanation of a very complex phenomenon. Since the purpose of this study guide is to help prepare the blaster for certification and not to discuss high explosives theory in detail, the reader is encouraged to seek information from other sources, including some of the selected references in Appendix H.

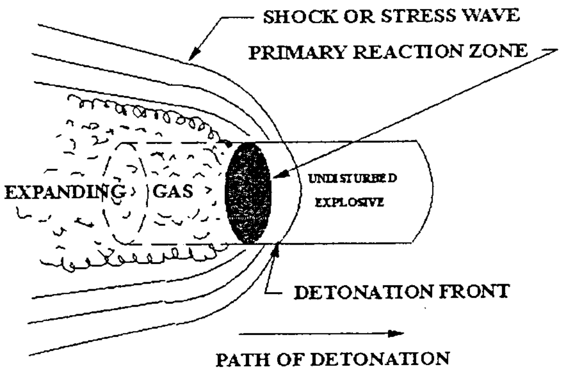


Figure 1.2

PHYSICAL PROPERTIES:

Today's commercial explosives market has many types of explosives available. Each explosives has been designed for optimum performance in a specific type of blasting environment. The characteristics of an explosive can be identified by its physical properties. These properties are identified below:

DENSITY

The density of an explosive is its weight per unit volume, usually in grams per cubic centimeter (g/cc). The density may also be expressed as specific gravity which is the ratio of the density of the explosive to that of water, 1.0 g/cc. Table 1.A shows typical densities for ACME products. A product chart similar to this can be obtained from your explosive supplier.

TABLE 1.A

ACME EXPLOSIVE PRODUCTS

PRODUCT	DENSITY - g/cc
ANFO	0.85
ANFO - HD	1.05
Emulsion	1.30
10-90 Blend	1.10
25-75 Blend	1.25
50-50 Blend	1.35
Water Gel A	1.10
Water Gel B	1.15
Water Gel C	1.25
Dynamite A	1.25
Dynamite B	1.40
Cast Booster	1.40
Pre-split	1.10

The density of an explosives is important for several reasons:

1. Density may affect the sensitivity of an explosive. This is discussed later under sensitivity.
2. Because water has a density of 1.0 g/cc, the density of an explosive to be used in water must have a density greater than 1.0 g/cc. Any explosive with a density less than 1.0 will

float which may result in decoupling of the explosive column and misfires. The density of commercial explosives ranges from about 0.8 g/cc for loosely packed ANFO to about 1.5 g/cc for some dynamites. Note: Drill cuttings and sediment will increase the density of water in a borehole. Care should be taken during hole loading and an explosive of sufficient density should be used. Also proper stemming is a must.

3. Density is a function of how much explosive can be loaded into a given borehole. Loading density, the weight of explosive per unit length of charge at a given diameter and expressed in pounds/foot, is discussed in detail in Chapter 3, "Blast Design".

VELOCITY OF DETONATION

The velocity of an explosive is the speed at which the detonation wave (shock front) moves through the explosive column. Depending on the borehole diameter, degree of confinement and type of explosive, this can vary from about 5,000 ft/sec to about 24,000 ft/sec. Detonation velocity is directly related to the explosives brisance or shock energy discussed below.

The detonation velocity of most commercial explosives, especially blasting agents, can be increased by increasing charge diameter, increasing density (to a point below its critical value), decreasing particle size, and increasing confinement. Every explosive has an ultimate or ideal velocity known as the hydrodynamic velocity.

SENSITIVITY

Sensitivity is the ease with which an explosive can be initiated. It is measured in several ways including cap sensitivity, drop test, bullet test, friction test, air gap test, and others. As an example, sensitivity to a No. 8 test blasting cap is used to determine if an explosives can be rated as a blasting agent. Table 1.B indicates typical explosive sensitivity. Explosives must have a sufficient degree of sensitivity to insure the entire charge column will detonate once initiated. An explosive charge with a low degree of sensitivity may fail to propagate along its entire length if it is not properly confined or its diameter is too small.

TABLE 1.B

ACME EXPLOSIVE PRODUCTS	
PRODUCT	SENSITIVITY
Dynamites	Moderate to High
Cast Boosters	Moderate
Water Gels	Moderate to Low
Emulsions	Moderate to Low
Blends	Low
ANFO Products	Low

WATER RESISTANCE

Water resistance is the ability of an explosive to withstand exposure to water without losing its sensitivity or efficiency. There is a wide range of water resistance among explosives. This can be accomplished by the explosive ingredients, the packaging, or both. Gelatin dynamites, water gels, slurries, emulsions, high percent emulsion blends, and cast boosters all afford an acceptable level of water resistance. ANFO and low percent emulsion blends have little or no resistance to water and should not come in contact with water.

Because water is ever present in blasting, many products and devices have been developed to handle it. Dewatering, hole sleeving, down-hole product pumping, and specialty explosives such as water resistant ANFO, pelletized TNT, and pourable water gels are all available in addition to the conventional packaged and bulk products. In many cases a combination of the above are used.

BRISANCE ENERGY

As discussed above, the brisance energy is directly related to an explosives detonation velocity and the shock wave it produces. Especially critical in hard to shoot rock, the brisance energy induces a shattering action which stresses and conditions the rock mass allowing more effective utilization of expanding gases.

WORK ENERGY

Work energy is the thermodynamic energy resulting from the rapid expansion of gaseous products generated by explosive detonation. This gas generation causes fragmentation and displacement of the rock mass. It is expressed in absolute terms by weight (calories/gram) and bulk or volume (calories/cubic centimeter). It is also expressed in relative terms (relative weight strength and relative bulk strength) using ANFO as a base equal to 100.

The term strength, traditionally associated with the strength markings of different dynamite grades, has little correlation with the effectiveness of an explosive in blasting and has no meaningful relationship with modern commercial explosives such as ANFO, water gels and emulsions. Historically the term was a measure of the percent of nitroglycerin used in straight dynamites. As the ingredients in straight dynamite were replaced or augmented by other energy producing substances, other methods have evolved. Today energy is theoretically calculated by computer utilizing the heat of formation of the various explosive ingredients, and other parameters such as gas volume, pressure and temperature.

DETONATION PRESSURE

The detonation pressure of an explosive is the pressure associated with the detonation wave moving through the explosive column. For commercial products, it can range from about 5 to 200 Kilobars (Kb). Detonation pressure is an important factor in determining priming requirements. For efficient explosive column detonation the detonation pressure of the donor explosive (booster) should exceed that of the receptor explosive (blasting agent).

SENSITIVENESS

Sensitiveness, frequently confused with sensitivity, refers to the propagating ability of an explosive. Explosives charges with high sensitiveness may mass detonate due to initiation by the pressure impulse of the first hole detonation, rather than detonating independently at their predetermined delay interval.

DYNAMIC PRESSURE RESISTANCE

Most ammonium nitrate based commercial explosives (ANFO, emulsions, water gels, etc.) are air sensitized. Two conditions exist that may squeeze the air out of the product before it detonates, causing it to fail. The first is the pressure impulse from an adjacent detonated hole. The second is hydrodynamic head pressure caused by the weight of water in a deep waterfilled hole. This desensitization is commonly referred to as "Dead Pressing". Close patterns, wet, laminated geology, poor relief, etc. are conditions that may result in dead pressing. If these conditions exist, a product with dynamic pressure resistance should be considered. Many emulsion and water gel products achieve pressure resistance by adding glass micro-balloons or other sensitizers.

TEMPERATURE RESTRICTIONS

Explosives are temperature sensitive. Commercial explosives, unless manufacturer specified, should not be used under conditions exceeding 150°F. Temperature exceeding this could result in explosive decomposition, deflagration or premature detonation. Low temperatures also effect explosives. Because cold temperatures effect explosive sensitivity, manufacturer's low temperature specification on priming and use should be consulted.

FUME CLASSIFICATION

In the detonation of explosives, poisonous gases, including carbon monoxide and nitrogen oxides, are produced. The quantity is dependent on a number of factor such as product formulation, product application, and product environment. In open work, fumes normally are of little concern. In confined areas and in underground work, the type of explosive must be considered. Product formulations for these type operations are tested and given a fume classification. Note: Some fumes may still be generated due to blasting conditions.

PRIMING REQUIREMENTS

An explosives sensitivity and the ambient temperature at which it is applied should be considered in determining priming requirements. Consult the manufacturer's priming recommendations.

SHELF LIFE

Shelf life is the maximum recommended time an explosive can be stored and still used without a reduction in its performance. It is the period of time between manufacturer and the eventual breakdown or decomposition of ingredients in the explosive. Actual shelf life can be affected by storage conditions, ambient temperature, and the product's chemical stability.

PACKAGING

Packaging is used to provide handling characteristics, charge shape, charge rigidity, tampability, water resistance, and abrasion resistance. The selection of packaging is based on the loading conditions encountered.

SAFETY CHARACTERISTICS

Storage, transportation, and handling requirements must often be taken into consideration when selecting explosives. Application, regulations, and other factors may dictate types, grades, and brands.

COST

The cost of the explosive must be evaluated. Many times the explosive with the cheapest price is not the explosive with the lowest cost.

This study guide is intended to provide the blaster with a general overview of explosive physical properties. For specific application problems, the blaster is encouraged to seek explosives selection advice from the supplier.

TYPES OF EXPLOSIVES AND BLASTING AGENTS

Explosives are divided into three distinct hazard categories: High Explosives, Low Explosives, and Blasting Agents. These categories are used to define how the explosive should be transported, stored, and utilized. Storage and transportation will be covered in a subsequent chapter. The utilization of the explosive depends on the type of material to be blasted, conditions of the blast bench, the blast design, cost, and many other factors.

A *high explosive* is one characterized by very high rate of chemical reaction, high pressure development and the presence of a supersonic (faster than the speed of sound) detonation wave in the explosive. In the detonation both brisance energy (shock energy) and work energy (gas energy) are produced. A second characteristic is its sensitivity. One of the confirming tests is the initiation with a No. 8 test cap. Some examples of high explosives are dynamite, blasting gelatin, TNT, PETN, and some water gels, slurries and emulsions.

Low explosives, on the other hand, react slower than the speed of sound, and are not characterized by a detonation wave. They burn at a rapid, but slower rate called deflagration. Only work energy (gas energy) is produced in a deflagration. A typical low explosive is black powder.

Blasting agents are materials or mixture of materials, consisting of oxidizer and fuel, intended for blasting, that meets prescribed criteria for insensitivity to initiation. There are several test requirements used to determine whether an explosive can be classified as a blasting agent. Probably the most notable is that the finished product as mixed for shipment and use, <u>cannot be detonated by a No. 8 test cap</u>. Blasting agents may have the blasting characteristics of either high or low explosives, but for commercial use, they typically have the blasting characteristics of high explosives.

For purposes of transportation under the Department of Transportation (DOT), explosives classification must conform to UN Classifications. Explosives classification is discussed in more detail in Chapter 7, Transportation & Storage and Appendix E, Federal DOT Explosives Classification.

Although there are many brand names, commercial explosives can be grouped into the following groups:

ANFO & ANFO Products
Emulsions & Emulsion Blends
Water Gels & Slurries
Dynamites
Black Powder
Cast Boosters
Specialties (PETN, TNT, Etc.)

ANFO & ANFO Products

The most common blasting agent is a mixture of 94% Ammonium Nitrate and 6% Fuel Oil, commonly referred to as ANFO. The AN, in the form of small spheres (prills), is porous like a sponge, to soak up the fuel oil. When properly mixed, the reaction products are CO_2, H_2O, N_2 and 890 cal/g. If not properly manufactured or if disrupted by some outside medium such as water or poor priming, the resulting imbalance of fuel and oxidizer will generate carbon monoxide (CO) and oxides of nitrogen (NO_x), both of which are poisonous fumes. There is also a marked decrease in the explosive energy and velocity (Figure 1.3).

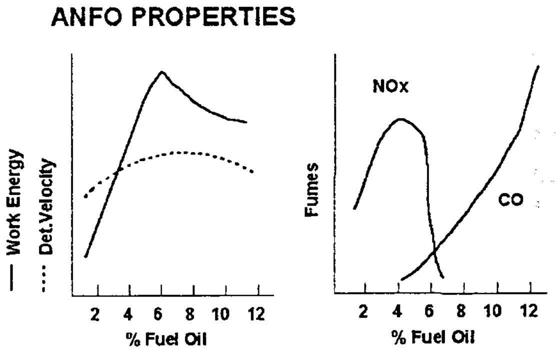


Figure 1.3

ANFO has a hydrodynamic velocity of approximately 15,600 ft/sec. Like all basting agents, its actual velocity is a function of the explosive column diameter (Figure 1.4). A larger diameter borehole will detonate at a greater velocity than a smaller diameter borehole.

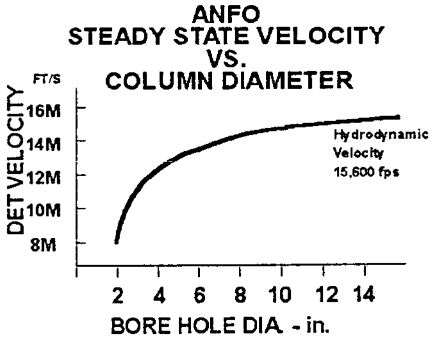


Figure 1.4

One major problem with ANFO is its poor water resistance. Water will quickly dissolve the ammonium nitrate prills, liberating the fuel oil which coagulates. Because its specific gravity is less than water, the oil migrates upward in the explosive column. This separation of fuel and dissolved oxidizer results in poor detonation or even failure. One sign that wet conditions existed is the orange cloud of nitrogen oxides evident after detonation.

The primary reason for ANFO's wide acceptance is its handling characteristics, its low cost and its gas generation per unit weight capabilities. Most ANFO used today is mixed and handled in bulk. Shipping, storage and loading are all designed for high volume operation and with today's modern equipment, blasting agent can be bulk loaded directly into the borehole in minutes (Figure 1.5). For smaller jobs, ANFO is still available in 50 pound paper bags (Figure 1.6).

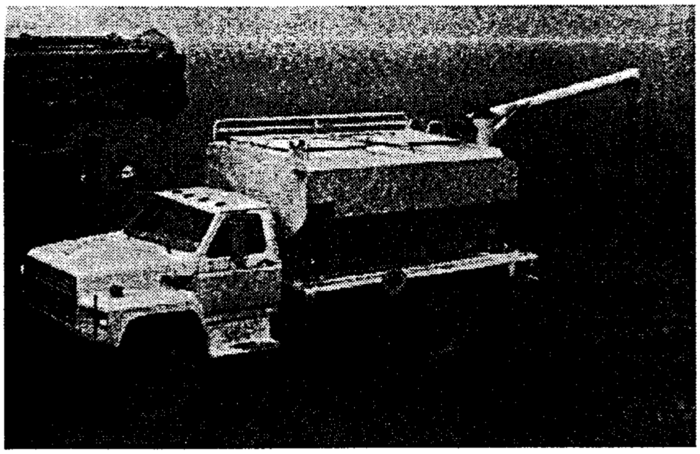


Figure 1.5

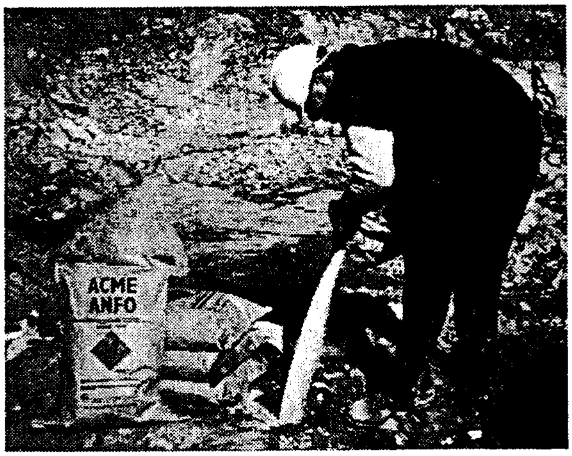


Figure 1.6

Because of its popularity, many added products have evolved from ANFO. Aluminum (Al) has been added to increase the energy output. The addition of 18.4% Al will increase the energy from 890 cal/g to 1620 cal/g. The addition of 21.3% TNT increases the energy to 1010 cal/g. A product called ANFO-WR uses a guar compound to make ANFO water resistant as well as boost its fuel energy. A high density mini-prill ANFO (Figure 1.7) has also been developed which uses a special tacified oil. This product, used in large diameter holes, has demonstrated energy values greater than common ANFO.

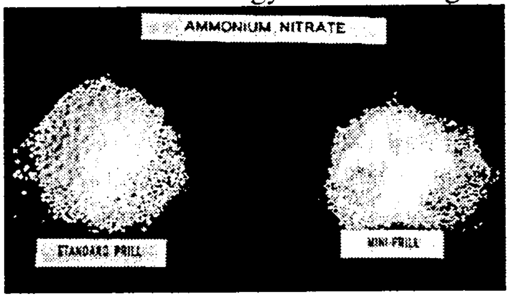


Figure 1.7

To allow ANFO to be used in wet holes, ANFO-HD was developed. This product is manufactured by crushing the AN prills (increasing density to approximately 1.05 g/cc), adding fuel oil and packing it into a water resistant package (Figure 1.8). Other additives are also used as discussed later.

Figure 1.8

Storage and handling of ANFO can be affected by everyday weather. Ammonium nitrate is hygroscopic and will readily attract moisture from the air, slowly dissolving itself. This should be kept in mind when storing for extended periods of time where the humidity is high. Also, ammonium nitrate is subject to phase changes at 0°F and

90°F. At these temperatures, changes in the crystal structure will cause the prills to break down into finer particles. This may alter both the storage and handling characteristics as well as the blasting agent's performance. During periods of potential temperature cycling, purchase freshly made product in quantities needed to avoid extended storage and locate storage so as to minimize exposure. Also bins and trucks should be cleaned periodically to remove fines and caked product.

EMULSIONS & EMULSION BLENDS

The universal acceptance of ANFO led explosive manufacturers to investigate adaptations to overcome its deficiencies such as velocity limits and water resistance. One such product is emulsions. An emulsion is similar in chemical composition to ANFO in that it contains ammonium nitrate and oil. In an emulsion the ammonium nitrate is dissolved in water as a super saturated solution (a solution containing the maximum dissolved AN salt possible). The solution is mixed with the oil and an emulsifier which enables the water/oil mixture to co-exist and not separate. The mixture is sheared which causes the AN solution to atomize within the oil resulting in a product that has the appearance and consistency of mayonnaise (Figure 1.9). The AN solution droplets are approximately 2 microns in size or about 1/1000th of the 2 millimeter diameter for a prill. This finer particle size increases both velocity and sensitivity. Since the droplets are suspended in an oil phase, the product is also water resistant.

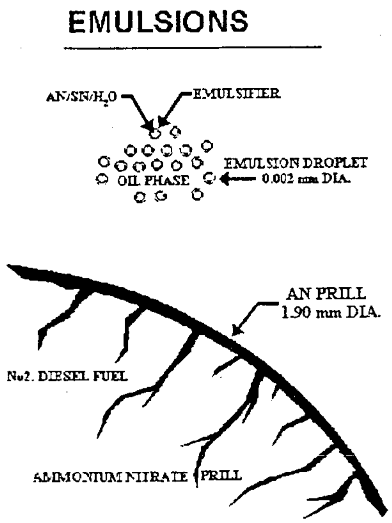


Figure 1.9

There are many variations in emulsions, but probably the most noteworthy is emulsion blends. The desire for minimum cost and the control of physical properties such as density, velocity, energy, pumpability, and water resistance has resulted in the blending of emulsions with ANFO. The changing of blend ratios can provide the required explosive physical properties (Figure 1.10) for most blasting conditions. Bulk handling equipment (Figure 1.11) has been designed to take advantage of this. Based on the ratio, blends can be delivered to the borehole by either augering or pumping. The blaster can customize his hole loading in the field as conditions warrant. Emulsions and blend products are available as bulk and packaged products.

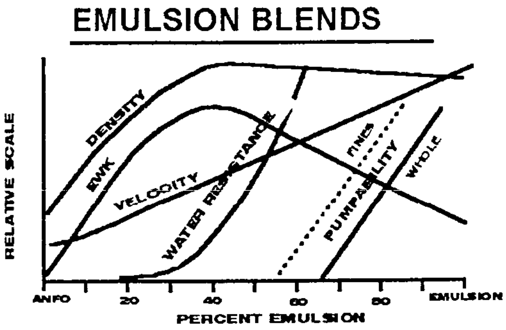


Figure 1.10

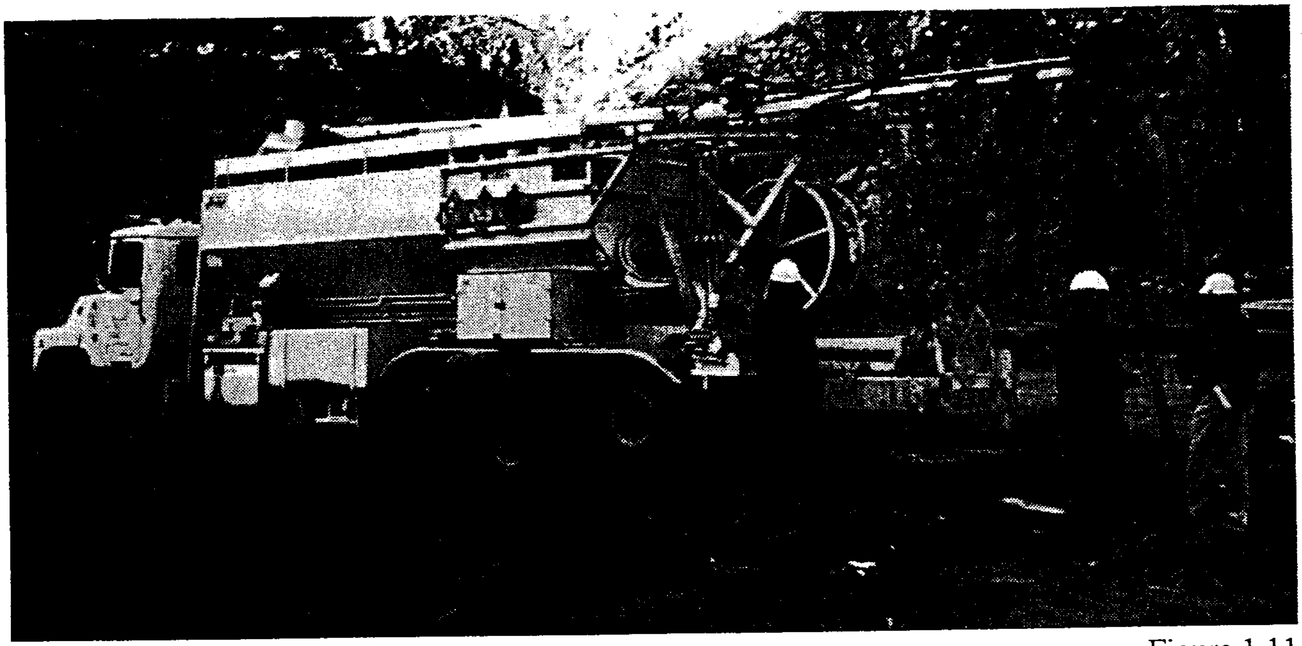


Figure 1.11

WATER GELS & SLURRIES

In the 1950's, research programs were undertaken to eliminate nitroglycerin as the basic ingredient for cartridge explosives. Building on the safety characteristics of ammonium nitrate blasting agents, while attempting to overcome their deficiencies such as water resistance, velocity limitations and sensitivity, water gels and slurries were introduced into the explosive marketplace.

Although similar, water gels differ from slurries. Both products consist of oxidizers, fuels and other solid and liquid ingredients. Water gels, however, utilize a sensitizer such as monomethylamine nitrate and a cross linking agent such as guar gum. The latter prevents ingredient separation, provides water resistance and gives the product the consistency of Jello. Slurries on the other hand utilize a thickener to prevent ingredient separation and promote water resistance. Their consistency is more fluid than water gels.

Water gels and slurries are manufactured as both cap sensitive high explosives and as blasting agents. These products can be pumped through hoses for direct loading into boreholes from bulk trucks or are available in cartridges and bags (Figure 1.12). They are commonly used in wet holes and where higher pressures and velocities are needed, such as toe loads at the bottom of the borehole and in harder to shoot rock formations. They can be sensitized to shoot in smaller diameter boreholes down to less than one inch. Check with the manufacturer for further information concerning the properties and applications of water gels and slurries.

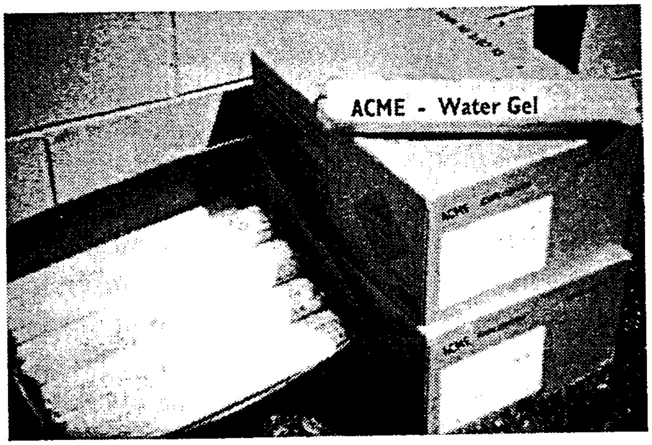


Figure 1.12

DYNAMITE

Dynamite was the principal commercial explosive for the past 100 years until the development of the modern blasting agents and products discussed above. Still used, it is just a few percent (less than 5%) of the market and almost always in small diameter holes. The primary remaining markets for dynamites are the construction industry and as primers for blasting agents.

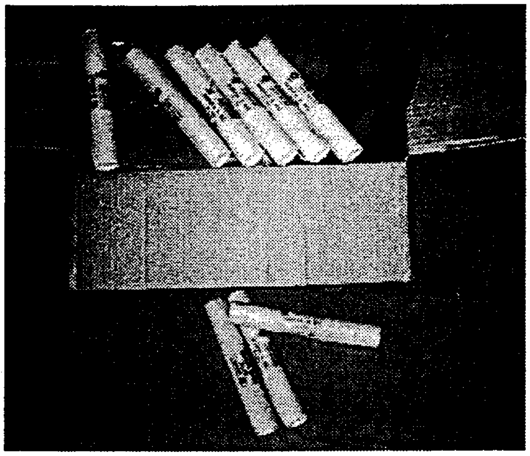


Figure 1.13

A nitroglycerine-based high explosive, dynamite may have a density as high as 1.6 g/cc, velocity to 25,300 ft/sec. and energy to 1600 cal/gram. Its sensitivity, although a plus in many applications, is considered by some to be a safety disadvantage in manufacture, transportation, use, and storage.

Many types of dynamite have been developed to match the different conditions and applications. They are available in a wide range of diameters, densities, packaging, types and energy (Figure 1.13). The three basic types of dynamite are: granular, semi-gelatin and gelatin. The last two contain nitrocotton which combines with the nitroglycerin to form a gel. Granular dynamites do not contain nitrocotton and have a grainy texture. Historically the principal energy source in straight dynamites was nitroglycerin. The strength rating of straight dynamite was based on the percent of nitroglycerin that it contained. In ammonia dynamites (sometimes called Extra Dynamites) ammonium nitrate and nitroglycerin are used as sensitizers.

BLACK POWDER

Black powder was the work horse of the explosive industry for years until it was replaced by dynamite around the turn of the twentieth century. Its current manufacture and use is very limited. Because of its very low velocity, it is not practical in most modern day mining applications. Its primary use today is the mining of dimentional stone, where an explosive is required to free the material from its location but fragmentation of the rock is not desired.

CAST BOOSTERS

A cast unit of explosive, normally a mixture of PETN and TNT (Pentolite) used to prime blasting agents and other less sensitive explosives. Although physical properties may vary, a pentolite cast booster has a density of about 1.4 g/cc and a velocity of about 22,000 ft/sec. These properties produce a very high detonation pressure which make it an extremely efficient booster for priming other explosives.

Figure 1.14

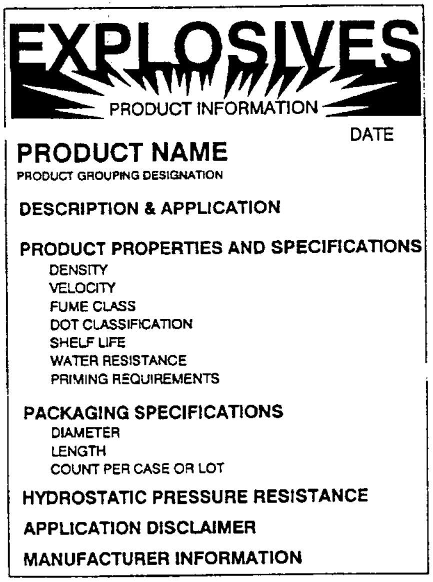
Cast boosters are normally configured to easily accept initiation devices such as detonators and detonating cords (Figure 1.14). They also are available in various sizes from ⅓ pound to 5 pound units. For details in primer application see Chapter 6, "Safety and Blasting Procedures"

SPECIALTIES

Although not commonly found in the commercial explosive market place, specialty items such as PETN, TNT, hot hole explosives, RDX, HMX, Composition B, and others are available on a limited bases. Many of these materials are present in the everyday explosive products that are utilized (eg. PETN is present in detonating cordand cas boosters). If questions concerning these products or an application develops requiring a specialty explosive, contact your explosive supplier.

PRODUCT INFORMATION

Every manufacturer publishes Product Information (PI) Sheets (Figure 1.15) and Material Safety Data Sheets (MSDS) (Figure 1.16) on their explosives. These sheets provide safety and physical property information useful to the blaster in design and loading. Futher information literature can be found in packaged explosive and initiation system boxes. This instructional information provides proper use techiques and warnings.



EXPLOSIVES

PRODUCT INFORMATION

DATE

PRODUCT NAME

PRODUCT GROUPING DESIGNATION

DESCRIPTION & APPLICATION

PRODUCT PROPERTIES AND SPECIFICATIONS
- DENSITY
- VELOCITY
- FUME CLASS
- DOT CLASSIFICATION
- SHELF LIFE
- WATER RESISTANCE
- PRIMING REQUIREMENTS

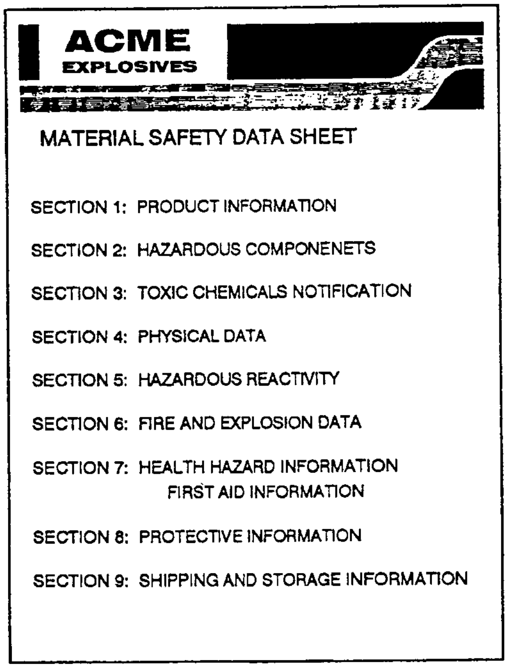
PACKAGING SPECIFICATIONS
- DIAMETER
- LENGTH
- COUNT PER CASE OR LOT

HYDROSTATIC PRESSURE RESISTANCE

APPLICATION DISCLAIMER

MANUFACTURER INFORMATION

Figure 1.15



ACME
EXPLOSIVES

MATERIAL SAFETY DATA SHEET

SECTION 1: PRODUCT INFORMATION

SECTION 2: HAZARDOUS COMPONENETS

SECTION 3: TOXIC CHEMICALS NOTIFICATION

SECTION 4: PHYSICAL DATA

SECTION 5: HAZARDOUS REACTIVITY

SECTION 6: FIRE AND EXPLOSION DATA

SECTION 7: HEALTH HAZARD INFORMATION
FIRST AID INFORMATION

SECTION 8: PROTECTIVE INFORMATION

SECTION 9: SHIPPING AND STORAGE INFORMATION

Figure 1.16

BLASTER'S NOTES

CHAPTER 2

INITIATION SYSTEMS

The most important element to the success of any multi-charge blast is the initiation system. Initiation systems, comprising of one or more components, are used to detonate the explosive charges in a pre-designed sequence. The proper sequencing of detonation provides fragmentation control , rock displacement, direction of movement, reduction of vibration and airblast, control of flyrock, highwall stability, reduction of potential misfires, and other production and safety aspects of blasting.

An initiation system consists of three basic parts:

1. An ignition energy source,
2. A distribution network that conveys the energy into the blastholes, and
3. An initiating device or detonator in the hole that initiates the explosive charge.

An initiation system may be either electric or nonelectric. The choice of the proper initiation system is determined by the type of explosive used, geology, environmental constraints, borehole temperature, hydrostatic pressure and the presence of extraneous electricity. The energy source may be an electrical generator, a condenser-discharge blasting machine, a power line, a heat source, such as a spark generator or percussion cap, or a match. The energy carried over the distribution network may be electricity, a burning fuse, an explosive detonation, or a dust or gas reaction. The initiating device is usually a detonator (blasting cap) in a high explosive booster which initiates the main explosive column. Figure 2.1 shows a typical detonator configuration. Commercial detonators, depending on manufacturer, may vary in output strength. Strength considerations should be based on the booster or explosive the detonator is required to initiate. With most boosters a Number 8 strength detonator is sufficient.

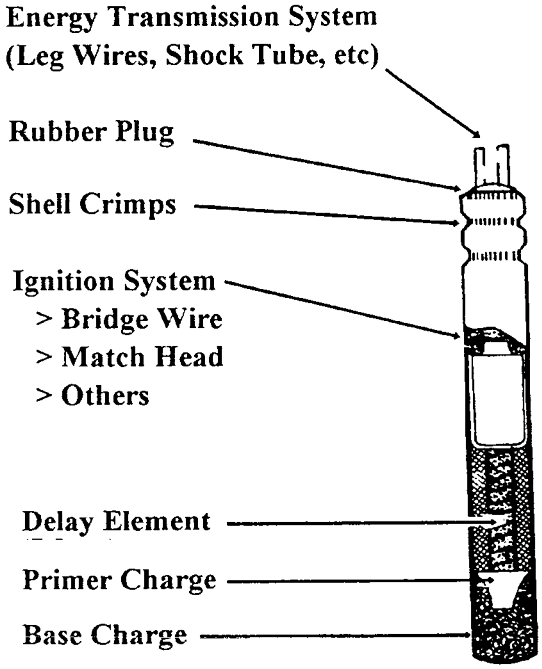


Figure 2.1

Detonators are manufactured in several delay configurations. Detonator delay is obtained by either pyrotechnic (burning) or electronic (microchip) technology.

1. Instant detonators (containing no delay element): This detonator fires within two

milliseconds after receiving its firing signal. A fuse cap is an instant detonator with the fuse providing its delay.

2. MS (millisecond) or SP (short period) delay detonators: Delay periods nominally run between 25 and 1000 milliseconds in 25 millisecond increments. Many manufacturers use period numbers corresponding to the delay (1=25ms, 2=50ms, 3=75ms, 4=100ms, ... , 40=1000ms).

3. LP (long period) or tunnel delay detonators: The LP delays typically include delay periods between 25 milliseconds and 15 seconds in delay intervals of ½ to 1 second. They are primarily found in underground mining where tight shooting conditions like tunnels, shafts, and drift rounds are found.

4. Coal mine delay detonators (used in shooting underground coal) Coal mine delay detonators are a special series of millisecond delays, nominally between 25 and 500 milliseconds, in delay intervals of 50 to 100 ms. They are typically recognized by the copper shell and iron leg wire construction. Unlike the other three systems, they are only manufactured utilizing electricity as the initiation energy signal.

Open pit coal, metal and non-metal mining, as well as general surface construction, normally utilize MS (millisecond) delay initiation. The instructional focus of this study guide will be on millisecond delay initiation.

Detonator identification is posted on both the shipping case and carton. Also color coding and tags are means for individual detonator identification. You are advised against using any detonator which cannot be positively identified.

ELECTRIC INITIATION

An electric detonator can be identified by the two insulated leg wires which extend from the top of the detonator shell (Figure 2.2). Leg wires of various lengths are available for various borehole depths. In a pyrotechnic delay detonator, the ends of these leg wires are connected by a small diameter bridge wire imbedded in a heat sensitive ignition mixture. When the proper electric current passes through the leg wires, the bridge wire heats, igniting this mixture, which in turn ignites the delay element (if present). After the delay element is consumed, it ignites the primer charge and finally the base charge or main detonator charge. Delay detonators utilizing microchip technology delay the energy input signal electronically before firing the primer and base charges. These detonators have higher delay precision than those utilizing pyrotechnics.

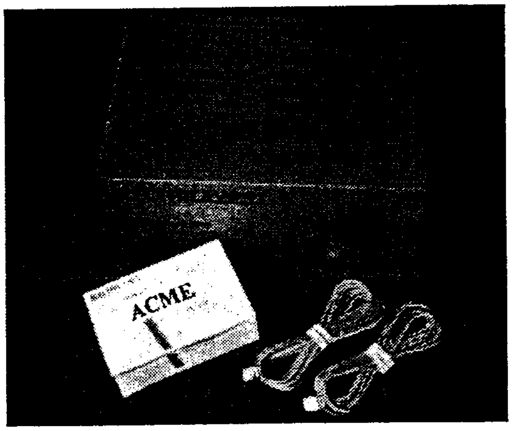


Figure 2.2

It is important to use manufacturer's recommended current level to initiate electric blasting detonators. Higher or lower currents may result in misfires or erratic delay timing. Also, because current requirements and bridge wire configurations may differ, all detonators in a blasting circuit must be from the same manufacturer. Using detonators from different manufacturers, a practice which is in violation of blasting regulations, may result in misfires.

CIRCUIT CONFIGURATIONS

There are three basic types of electric blasting circuits: series circuit, parallel circuit, and parallel series circuit:

A series circuit is a circuit which has only one path or loop through which the firing current may travel. A break or failure at any point in a series circuit will completely stop current flow. Every detonator in a series circuit will receive the same amount of current at the same time. It is easy to check a simple series circuit with a blasting galvanometer. The primary disadvantage to a series circuit is the number of detonators that can be fired at one time. For most blasting machines it is limited to 40 or 50 units, depending on the leg wire length. Figure 2.3 shows an example of series circuits.

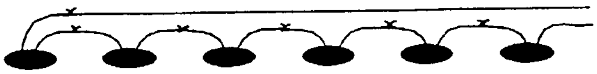


Figure 2.3

A parallel circuit is a circuit wired so that the current is supplied to each component (or detonator) along a separate path. Parallel circuits are usually not used in surface mine blasting because the large number of detonators would require more current and thus a heavier gauge lead line and a greater power source. If a parallel circuit is utilized, it is important that each detonator have the same resistance so they all receive equal current. A break in one branch will not prevent current from passing through other branches. Figure 2.4 shows an example of a parallel circuit.

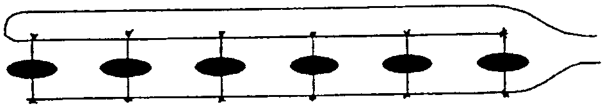


Figure 2.4

A parallel series circuit (sometimes called series-in-parallel), is a circuit where two or more series circuits of detonators are connected in parallel. By providing a multiple path, overall circuit resistance is reduced and a larger number of detonators can be fired utilizing the same blasting machine. It is important in designing a parallel series circuit that each parallel series have approximately the same resistance, so that when initiated each series receives the same amount of current. Unbalanced series will cause an imbalance

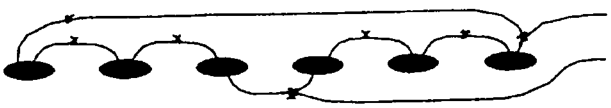
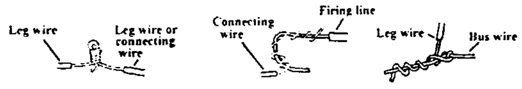


Figure 2.5

in current distribution and may result in misfires. Figure 2.5 shows an example of a series-in-parallel circuit.

No matter which type of electric blasting circuit utilized, several procedures should be followed in connecting the blast circuit.

1. All wire splices should be clean, secure and not touching the ground or water. The recommended wire splices for blasting circuits are shown in Figure 2.6. To splice two small wires, they are placed parallel to each other, looped and twisted together. To connect a small wire to a large wire, the small one is wrapped around the large one.



LIGHT GAGE TO LIGHT GAGE (TWISTED LOOP)

LIGHT GAGE TO HEAVY GAGE

Figure 2.6

2. Connecting wire, a disposable small gauge insulated wire, normally about 20 gauge, should be used to connect the detonator leg wires to the firing line or firing board. This wire should only be used once.

3. The firing line should be constructed of two solid conductor copper wires, 12 or 14 gauge, with a tough, waterproof insulation. The minimum length of a firing line is 450 ft. It may be reused from shot to shot but should be inspected frequently and replaced when necessary. If a sequential timer is utilized, the firing cable and board furnished with the system should be used. The sequential timer cable must also be a minimum of 450 feet in length. If the blast circuit is connected in parallel and a bus wire is to be used, it is considered to be an extension to the 450 foot firing line. It should be the same gauge as the firing line and may be bare or insulated. To assure equal current distribution to each series, one bus wire should be reversed as shown in Figure 2.4.

ELECTRIC BLASTING CIRCUIT CALCULATIONS

Ohm's Law is the governing factor in determining the wiring configuration of any electrically initiated blasting circuit. This law states that the current (in amperes) supplied to any electrical circuit is equal to the potential (in volts) of the power supply divided by the resistance (in ohms) of the circuit.

Equation 2.1: $I(\text{amps}) = V(\text{volts})/R(\text{ohms})$

This equation may also be solved for the volts ($V=IR$) or for the resistance ($R=V/I$). If the resistance of any blasting circuit is calculated and the output voltage of the blasting machine is known, the amperage to the detonators may be calculated using Ohm's law. As a rule of thumb, each detonator connected in a series circuit or in a parallel series circuit and fired with a capacitor discharge (CD) type blasting machine (direct current) should receive a minimum of 1.5 amps to reliably fire. Table 2.C indicates the current need for firing electric detonators. You should check your detonator supplier to determine the recommended firing current requirements.

To calculate the resistance of a blasting circuit, first calculated the resistance of the detonator circuit (series, parallel, or parallel series). Each electric detonator manufacturer publishes a nominal resistance table for the various wire types and lengths marketed. Table 2.A is an imaginary sample of a typical detonator resistance chart. Based on ACME detonators utilized, the resistances from this chart can be used to determine the resistance of the detonator circuit. The total blasting circuit resistance adds the sum of the resistances of the connecting wire and firing line to the resistance of the detonator circuit.

Table 2.A

Nominal Resistance for ACME Detonators

Copper Wire		Iron Wire	
Wire Length (ft)	Resistance (ohms)	Wire Length (ft)	Resistanc e(ohms)
6	1.75	6	2.55
8	1.85	8	2.90
10	1.90	10	3.25
12	2.00	12	3.60
14	2.05	14	4.00
16	2.15	16	4.30
20	2.30	20	5.00
24	2.50	24	5.70
30	2.25	N/A	--
40	2.50	N/A	--
50	2.80	N/A	--
60	3.00	N/A	--
80	3.70	N/A	--
100	4.05	N/A	--

SERIES CIRCUIT: The resistance of a series circuit is the sum of the individual resistances of each detonator in the circuit (Equation 2.2).

Equation 2.2: $R_T = R_1 + R_2 + R_3 + \ldots + R_n$

where R_T = total resistance and n is the number of detonators. $_1$R is the resistance of the first detonator, R_2 the second, up to R_n, the resistance of the last.

In many blasting applications the resistance of each individual detonator is the same. If this is the cases, then the total resistance can be calculated by multiplying the resistance of one detonator by the number of detonators, Equation 2.2A.

Equation 2.2A: $R_T = R_1 \times n$

Example Problem
A blast containing 20 ACME delay detonators with 24 foot copper leg wires are wired in series. The resistance of one detonator is 2.50 ohms. Find the total resistance of the detonator circuit.

Using equation 2.2A, multiply the resistance of one detonator by the number of detonators.
$R_T = 20 \times 2.50 = 50.0$ ohms

PARALLEL CIRCUIT: In a parallel circuit, each detonator has its own circuit. The resistance of a parallel circuit is the reciprocal of the sum of the reciprocal of each detonator resistance (Equation 2.3).

Equation 2.3:
$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n}$$

where R_T = total resistance and n is the number of caps. R_1 is the resistance of the first detonator. That resistance is reciprocate (divided into 1). R_2, the resistance of the second detonator is also reciprocated. Each of the other detonator resistances are then reciprocated. All of the reciprocated resistances are then added together. The total resistance of the parallel circuit is the reciprocal of the sum.

In many blasting applications the resistance of each individual detonator is the same. If this is the cases, then the total resistance of the parallel circuit can be calculated by dividing the resistance of one detonator by the number of detonators, Equation 2.3A.

Equation 2.3A: $R_T = R_1 / n$

Example Problem:
A blast containing 20 ACME electric detonators is wired in parallel. Each detonator used has a resistance of 2.50 ohms. What is the resistance of the detonator circuit?

Using Equation 2.3A, divide the resistance of one detonator by the number of detonators.
$R_T = 2.500 / 20 = 0.125$ ohms

PARALLEL SERIES CIRCUIT: In a parallel series circuit, individual detonators are divided into two or more groups. The detonators in each group are then wired in series. Determination of the optimum number of parallel series groups can be determined by the use of a chart developed by the blasting machine manufacturer (Figure 2.7) or by the S-squared formula (Equation 2.4). The purpose of optimizing the number of parallel series circuits is to insure that each series will receive sufficient current to fire all of the detonators.

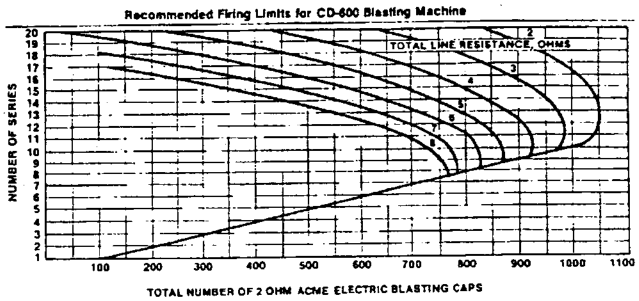


Figure 2.7

Equation 2.4: $$S = \sqrt{\frac{R_{TS}}{R_C + R_F}}$$

where: S = number of series
R_{TS} = total resistance of all detonators in series
R_C = connecting wire resistance (ohms)
R_F = firing line resistance (ohms)

To insure proper current distribution when the circuit is energized, each series should have, as close as possible, the same resistance. The series groups are then wired in parallel with each other. Calculating the resistance of a parallel series circuit is a three step process. You must first calculate the number of parallel series and the number of detonators in each of those series (Equation 2.4). Next you must determine the resistance of the individual series (Equations 2.2 or 2.2A) and then determine the total resistance after connecting the series circuits in parallel (Equations 2.3 or 2.3A).

Example Problem
A blast containing 120 ACME delay detonators, each with a resistance of 2.50 ohms, is to be wired in parallel series.

Using equation 2.4, we first determine the optimum number of parallel series circuits to be used. S = square root of [120 x 2.5 / (6.09 + 1.588)] = 6.25 series, rounding off to 6 parallel series. With the 120 detonator blast wired in 6 parallel series, each series would have 20 detonators (120 / 6 = 20). It is important to remember in designing a parallel series circuit that each series should have, as close as possible, the same resistance. Using equation 2.2A, multiply the resistance of one detonator by the number of detonators in one series. R_S = 20 x 2.50 = 50.0 ohms. Since each series has the same number of detonators, each having the same resistance, the resistance for each of the six series will be the same. Using equation 2.3A, divide the resistance of one series by the number of series connected in parallel. R_T = R_S / n = 50 / 6 = 8.333 ohms. This is the total resistance of the detonator circuit.

TOTAL BLASTING CIRCUIT: As mentioned above, the total resistance of a blasting circuit consists of the resistance of the detonator circuit, the connecting wire and the firing line. Since these three components are normally connected in a series configurations, the total resistance of the blasting circuit is the sum of the three individual resistances (Equation 2.5). The resistance for both connecting wire and the firing line can be developed from a chart displaying various wire gauges and their resistance per unit length. A sample chart is shown in Table 2.B. Note that the larger the wire diameter (smaller gauge number) the lower the wire resistance.

Equation 2.5: $R_T = R_D + R_C + R_F$

R_T = total resistance for a blasting circuit (ohms)
R_D = detonator circuit resistance (ohms)
R_C = connecting wire resistance (ohms)
R_F = firing line resistance (ohms)

Table 2.B

Resistance of Copper Wire

AWG Number	Ohms per 1,000 feet
6	0.395
8	0.628
10	0.999
12	1.588
14	2.525
16	4.02
18	6.39
20	10.15
21	12.80
22	16.14
23	20.36
24	25.67

Example Problem

A blast containing 30 ACME delay detonators, each with a resistance of 2.50 ohms is wired in series. The detonator circuit is connected to a 500 foot 12 gauge copper firing line with 120 feet of 20 gauge copper connecting wire. What is the total resistance of the blast circuit?

Using equation 2.2A, the resistance of the detonator circuit is 30 x 2.5 ohms = 75.0 ohms. From Table 2.B, the resistance per 1000 feet of 20 gauge copper connecting wire is 10.15 ohms. Since only 120 feet was used in the blast circuit, the resistance of the connecting wire is (120/1000) x 10.15 ohms = 1.218 ohms. From Table 2.B, the resistance of 1000 feet of 12 gauge copper fire line is 1.588 ohms. The firing line is 500 feet long and contains two conductors (wires). This results in a total wire length in the firing line of 1000 feet (2 x 500). The resistance of the firing line is (1000/1000) x 1.588 ohms or 1.588 ohms. Using equation 2.5, the total resistance of the blasting circuit is $R_T = 75.0 + 1.218 + 1.588 = 77.806$ ohms.

Table 2.C

Current Needed for Firing Electric Detonators

CIRCUIT	D.C. POWER	A.C. POWER
Single Cap	0.5 Amp	0.5 Amp
Single Series	1.5 Amps	2.0 Amps
Parallel	1.0 Amps Per Cap (min) 10.0 Amps Per Cap (max)	1.0 Amps Per Cap (min) 10.0 Amps Per Cap (max)
Parallel Series	1.5 Amps Per Series	2.0 Amps Per Series

ACCESSORIES

BLASTING MACHINES

The power source for an electric blasting circuit is either a blasting machine or a power line. Blasting machines are generally either a generator or a capacitor discharge (CD) type machine, the latter being the more dependable. Storage, auto, and dry-cell batteries are not recommended as their output is not consistent.

The generator blasting machines are the rack-bar (push down) or the key-twist type (Figure 2.8). The current output of these machines depends on the condition of the machine and the effort exerted by the blaster. It is recommended that only series circuits be used. Check the capacity limitations recommended for the machine before loading the shot.

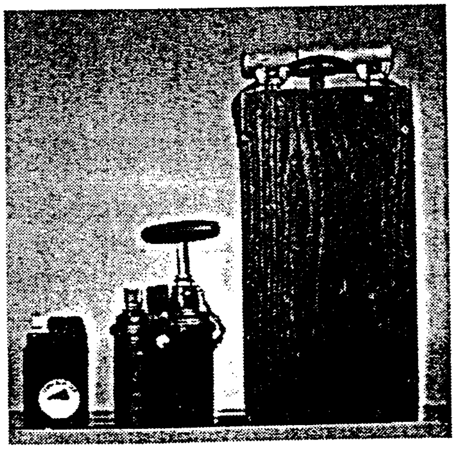


Figure 2.8

Capacitor (condenser) discharge blasting machines (Figure 2.9) use batteries to charge a series of capacitors. The capacitors store this energy until the fire button is pressed and then release it rapidly into the blasting circuit. They are available in a variety of designs and capacities, some that will fire over 1,000 caps in a parallel series circuit.

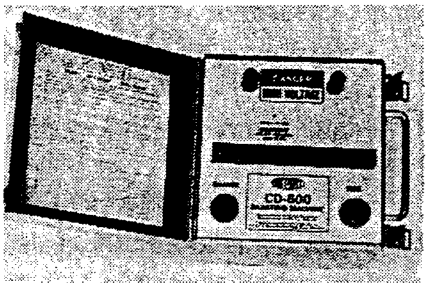


Figure 2.9

A sequential timing blasting machine (Figure 2.10) is a capacitor discharge type blasting machine. It contains 10 separate circuits for which the blaster can preselect a millisecond time interval sequencing. When the fire button is pressed, the first circuit energizes. After waiting the preselected time interval the second circuit energizes. This sequencing continues until all properly wired circuits are energized. When used with ms-delay electric detonators, the sequential timer provides a very large number of separate delay intervals and better timing control. Care should be taken in blast design to prevent cutoffs. If possible, have all holes energized before the first hole detonates. Also the blaster must continue to press the firing button until all circuits are energized. The sequential timer will discontinue its firing sequence as soon as the fire button is released or when it encounters an open circuit.

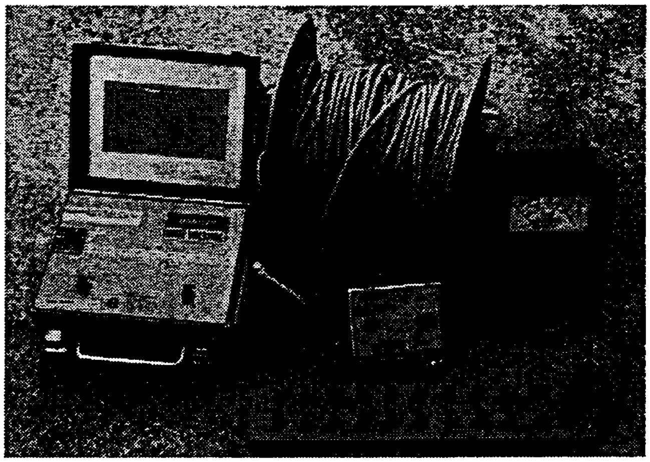


Figure 2.10

Power line blasting is not a recommended practice in open pit blasting. It is commonly found where parallel circuits are used. If power line blast initiation is to be used, the blaster should insure that the system is properly designed, preferably by an engineer familiar with the hazards and requirements. Precautions must be taken to prevent arcing which can result in erratic timing, hangfires, or misfires.

CIRCUIT TESTING

One of the primary advantages of electric initiation is that the energy distribution network can be checked for continuity. This check is done using a Blasting Galvanometer, Blasting Ohmmeter or Blasting Multimeter (Figure 2.11). The Blasting Galvanometer and Blasting Ohmmeter are only used to check the circuit resistance (measured in ohms). The Blasting Multimeter can be used to check resistance, AC and DC voltage, stray currents and current leakage (see below). Prior to performing a check with one of these instruments, the blaster should insure that the instrument has the words "Blasting" or "Blasters" on it. This indicates that the output of the instrument is limited to 0.05 amps which will not initiate an electric detonator. Use of an instrument not designed for blasting, could result in sufficient energy to cause premature initiation of the detonator circuit.

A continuity check of each detonator should be made before it is assembled into a primer for use. Although a test is conducted by the manufacture before shipment, this is a good practice for insuring reliable blast initiation. It is required by regulation that each detonator be tested for continuity after the hole has been loaded with explosives and prior to stemming. If leg wire integrity has been compromised, a new primer can be inserted into the hole prior to stemming. In both of these test cases, the leg wires should be reshunted after the test is completed.

When testing electric detonators or circuits containing them, use only meters marked

- Blasting Galvanometer
- Blasting Ohmmeter
- Blaster's Ohmmeter
- Blaster's Multimeter

Don't use any other test instrument.

Figure 2.11

After the blast has been loaded, stemmed and the blast circuit has been tied together, a preblast check should be conducted, consisting of both visual and resistance. The visual check is made by walking the shot while tracing each series to make sure all of the detonators have been connected to the circuit, that all splices are tight, intact, out of water, and insulated from earth and each other, and that the circuits are properly connected. The resistance check, using one of the blasting instruments above, is made to insure that the blasting circuit is hooked-up properly, that there are no broken wires or short circuits, that the resistance of the circuit is compatible with the power source, and the measured resistance compares favorably with the calculated value.

Electrical initiation has several problem areas that should be addressed by the blaster to insure safety and performance. These include current leakage, extraneous electricity, and misfires.

When some electric detonators, wired in series or parallel series and supplied with an adequate firing current, fail to fire, current leakage may be the cause. Conditions which result in current leakage are ragged boreholes damaging legwire insulation, saturated ground and water filled boreholes, highly conductive ground or ore, conductive explosives such as emulsions, water gels or slurry, or failure to insulate bare wire or splices from ground or each other. Measures for combating current leakage include using 25% fewer caps per circuit, using heavier gauge lead lines and connecting wires, insulating bare wire connections from ground or each other, increasing the current, or using a nonelectric initiation system.

Extraneous electricity is any electrical energy, other than the actual firing current or test current, which may be present in the blasting area. It exists in the form of electromagnetic induction, ground fault, static electricity, radio frequency (RF) energy, and lightning. Electric detonators should not be used if the presence of these stray currents is 0.05 amps or more. Stray currents come from heavy equipment or power systems in the area, and are carried by metal conductors or power lines. Instruments have been developed that can monitor for stray currents continuously and sound an alarm when an excess current is detected. Static electricity may be generated by pneumatic loading, particles carried by the wind (especially in a dry atmosphere) and by rubbing clothing or friction. Most electric detonators are static resistant. In the pneumatic loading of ANFO, a semiconductive loading hose and grounded vessel must be used to dissipate static build up. Also pneumatic loading, plastic borehole liners, and electric detonators should not be used in conjunction with each other. Broadcasting stations, mobile radio transmitters cellular phone, and radar installations present the hazard of RF energy. Information is available on transmission specifications and potentially hazardous distances in IME's Publication No.20. Electrical storms are a hazard for any type of initiation system, and when approaching or in the area, loading operations must cease and all personnel retreat to a safe location. High-voltage power lines present hazards of stray currents and attracting lightning. They also present a danger when part of the blasting wire or firing line is throwing onto the power line. Precautions should be taken when blasting in the presence of power lines.

Misfires, although rare with electric initiation due to the ability to check circuit continuity, do occur. The primary causes are current leakage, failure to have all circuits energized before the first hole detonates (see Chapter 4, Shot Timing), improper circuit wiring, or a faulty blasting machine. If a misfire is suspected with electric initiation, a minimum period of 15 minutes must be observed before reentering the blast area. Details in handling misfires are covered in Chapter 6, "Safety and Blasting Procedures".

NON-ELECTRIC INITIATION

Non-electric initiation was the first initiation system. With the advent of the electric delay detonator, the original systems gradually lost there appeal and were replaced. With recent improvements, non-electric initiation has turned the trend and become the system of choice in most surface blasting. Not only is it is not affected by stray current, radio frequency, and static electricity, but it also provides easier hookup, more design versatility, and has a limitless number of delay possibilities with no restrictions on initiation energy availability.

CLASSIFICATION AND CIRCUIT CONFIGURATION

There are four primary classifications of non-electric initiation. They are cap-and-fuse, detonating cord, low energy detonating cord, and shock tube. When selecting a non-electric system, some considerations are: system versatility and simplicity, adaptability for multi-path, multi-decking, and multi-priming, timing capability and accuracy, compatibility with other initiation systems and explosives, manufactured or cut-to-fit lengths, visibility, debris, noise, inventory and cost. Although non-electrics provide many advantages, some disadvantages exist and must be recognized. Because circuit continuity cannot be checked with a meter and must be done by visual inspection, misfires may occur. To avoid misfires, care must be taken during loading, hook-up and final visual inspection to insure system continuity is not compromised. If possible all in-hole detonators should be energized before the first hole detonates. Other considerations are to increase in-hole detonator delays, provide two paths of initiation to each hole, or reduce the shot size. If a misfire does occur with a non-electric initiation system, a minimum of 15 minutes (30 minutes for cap and fuse) should be observed before reentering the blast area.

CAP-AND-FUSE

Cap-and-fuse is the oldest explosive initiation system. Its use is almost non-existent in surface blasting today with the exception of limited use for secondary blasting and the initiation of other non-electric systems. Safety fuse has a core of black powder which is wrapped in layers of textiles and water-proofing materials. The standard fuse burns at 120 seconds/yard (1.5 feet /minute). The fuse should be tested before use to determine any effects storage, age, weather, etc. has had on its burn rate.

The fuse acts as both the energy conveying network and the delay timing element as it carries the enclosed flame to a fuse cap. The freshly cut fuse end is inserted into the open end of the cap, seated against the explosive without twisting, and crimped in place with a crimping tool (Figure 2.12). Regulations specify hotwire lighters, lead splitters or Ignitacord as approved ignition systems. One person may not light more than 15 fuses in a round. Proper use of cap-and-fuse requires as much or more skill and experience as other systems. For more detailed procedures on safety and use contact your supplier.

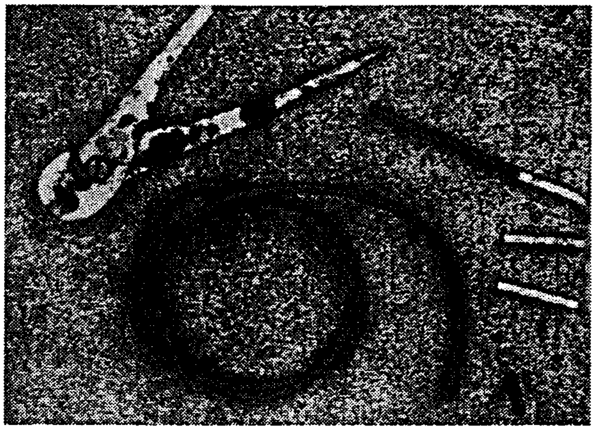


Figure 2.12

DETONATING CORD

Detonating cord contains a core of high explosive, usually PETN, wrapped in textiles, plastic and water-proofing materials (Figure 2.13). It is available in core loadings ranging from 15 to 400 grains per foot. Detonating cord has a detonation velocity of about 22,000 feet per second (~ 4.2 miles/second). When detonated, it sends a shock wave along its entire length, sufficient to initiate cap sensitive high explosive. Manufacturers should be consulted for recommendations on the use of detonating cord with various explosive products, since it may desensitize some blasting agents or negate inhole delays in more sensitive explosive columns. Detonating cord is adaptable to most

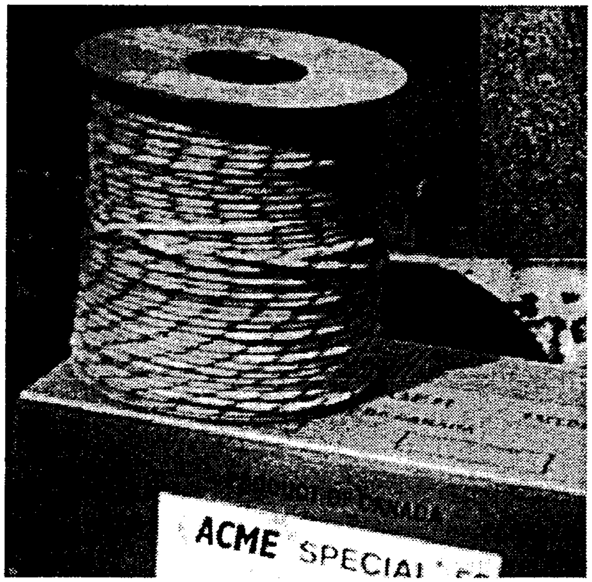


Figure 2.13

surface blasting situations and is commonly used as the initiation system for presplit and parting shots. Detonating cord can be used directly with a primer (instantaneous inhole delay) or with specially manufactured down hole millisecond delays (Figure 2.14) . The detonating cord used to transmit the energy signal down the hole is called a downline. The detonating cord used to carry the energy signal across the surface of the blast bench to each of the downlines is called a trunkline. Connections of downlines to trunklines and trunklines to trunklines are made by knots tied at right angles to each other (Figure 2.15). To provide initiation delay, the trunkline is cut and MS-delay surface connectors or Noiseless Trunckline Delays (NTD) (Figure 2.14) are inserted. Regulations require trunklines be designed to permit two paths of initiation to each borehole. Figure 2.16 illustrates a typical blast laid out with detonating cord.

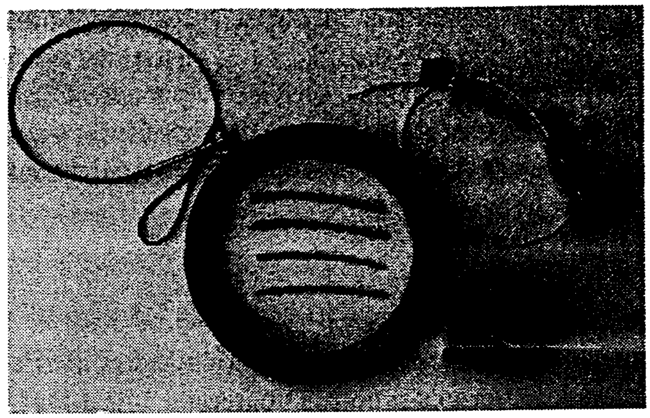
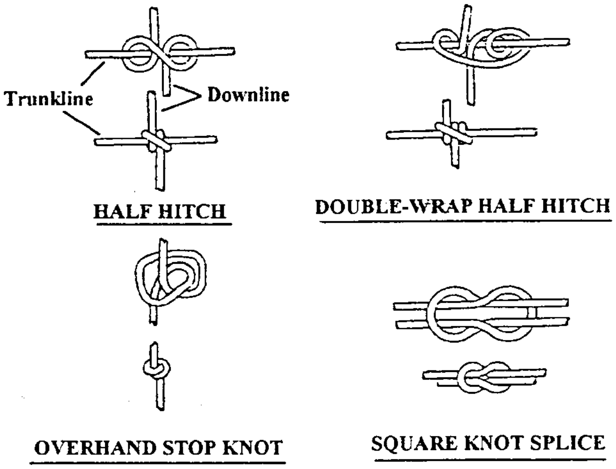


Figure 2.14

The main advantages of detonating cord initiation systems are their insensitivity and ruggedness, especially in severe wet hole conditions, in abrasive rock and in deep boreholes and their non-susceptibility to electrical hazards (except lightning). The chief disadvantages are the potential for cutoffs, high-frequency airblast (noise). and the disruption of the explosive charge and stemming.



HALF HITCH

DOUBLE-WRAP HALF HITCH

OVERHAND STOP KNOT

SQUARE KNOT SPLICE

Figure 2.15

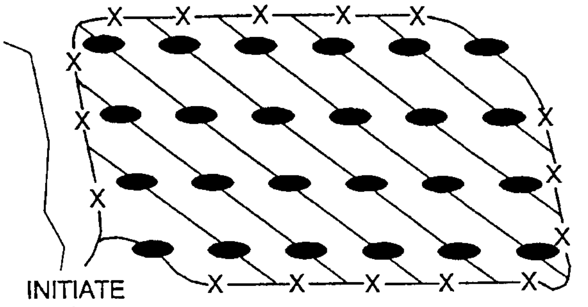


Figure 2.16

LOW ENERGY DETONATING CORD

Low energy detonating cord initiation systems are similar to detonating cord systems, except that the cord has a low core load, about 2.4 to 12 grains/foot. This low core load will not initiate most high explosives (exception some dynamites) and thus an inhole delay detonator is required. Although there are several low energy cords available, Detaline®is the most complete system (Figure 2.17). The system consists of three main parts:

1. The Detaline® cord, which has a core loading of 2.4-gr/ft, comes on a 2,700 foot spool. This low-energy cord is low in noise, insensitive to impact and fires at about 22,000

feet/second.

2. Detaline® ms-in-hole delays are available in two configurations: a tie on detonator or a sliding detonator (Detaslide®). Both configurations have 19 delay periods ranging from 25 to 1,000 ms.

3. The Detaline® ms-surface delays are plastic arrow shaped connectors. In the center of the connector is a nonelectric detonator which accepts a loop of the Detaline® cord in the tail of the unit and either a Detaline® cord or detonating cord downline (or both) in the pointed output end. There are 7 ms-delays (9, 17, 30, 42, 60, 81, 100) and an instant delay called a starter. Because of the insensitivity of the cord, surface delay connectors must be used instead of knots when splicing the cords together. The system has many advantages such as high versatility, cut to fit construction, high visibility, low inventory, low debris, and multi-path, multi-prime and multi-deck capabilities.

Figure 2.17

SHOCK TUBE

The shock tube system is one of the most popular non-electric initiation systems used in surface mining. Its general construction has a single hollow tube about 0.12 inch in diameter that extends out of the detonator. This tube has a thin coating of reactive material on its inside surface (about 0.1 gr/ft), which detonates at 6,000 fps. When initiated by detonating cord, a blasting cap or the spark from a percussion cap, this tube will reliably transmit a low energy spark by means of a shock wave similar to a mild dust explosion. This reaction is not strong enough to damage the tube.

There are several systems available utilizing this technology: Ensign Bickford, Dyno, ICI, and Austin all manufacture shock tube initiation systems. Some of the more common trade names are Primadet®, NTD, EZDet™ ,EZTL™, Nonel Super®, SnapDet™, SnapLine™, Exel™ , and Shock•Star™. All of the variations of the shock tube system (Figure 2.18) fall into four categories:

Figure 2.18

1. In-hole delay detonators are available in various manufactured downline lengths and various in-hole delays from 25 to 1000 millisecond. Long period delays are also available. A detonator is attached to one end of the shock tube and a hook connector for attaching to detonating cord is on the other.
2. Trunkline (surface) delay detonators are available in various manufactured lengths and various delays from 9 to 200 milliseconds. A detonator in a plastic shock tube connection block is attached to one end of the shock tube and a hook connector for attaching to detonating cord is on the other).
3. Combination inhole delay - surface delay units are available in various manufactured lengths with a variety of in-hole and surface delay combinations. The combination unit has an in-hole delay detonator attached to one end of the shock tube and a delay detonator in a plastic shock tube connection block on the other.
4. Shock tube lead-in line is available for use as a non-electric firing line.

There are many variations available with this system. One option is to use all the same in-hole delay detonators and provide hole to hole delay sequencing using surface delays. A sample of this piggyback delay hookup is shown in Figure 2.19.

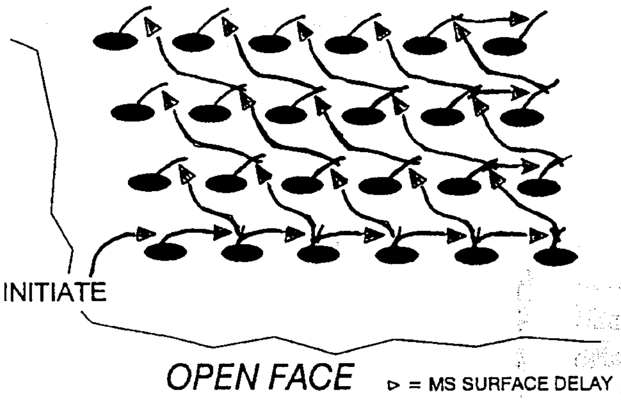


Figure 2.19

The advantages of the shock tube system are minimal airblast, no charge disruption, no effect by electrical hazards (except lightning), and versatile delay capability. The system is compatible with other non-electric initiation but specific hook-up procedures should follow manufacturer's recommendations to prevent possible cutoffs. Surface delays are directional (fire in only one direction). Care should be taken on hook-up to insure delays are properly connected both in configuration and direction. System checkout is visual.

The shock tube delay connection block is available in two basic configurations: the bunch block and easy snap block. The bunch block contains a high energy detonator and should be covered with earth to prevent shrapnel from cutting unfired trunklines. The bunch block can accept both shock tube or detonating cord, however both should not be inserted into the same block. If this is done the higher velocity detonating cord may sever the shock tube resulting in a misfire. If both detonating cord and shock tube are to be used together, the detonating cord should be inserted into the bunch block and the shock tube connected to the detonating cord with the hook device (Figure 2.20). The easy snap blocks contain a low energy detonator and

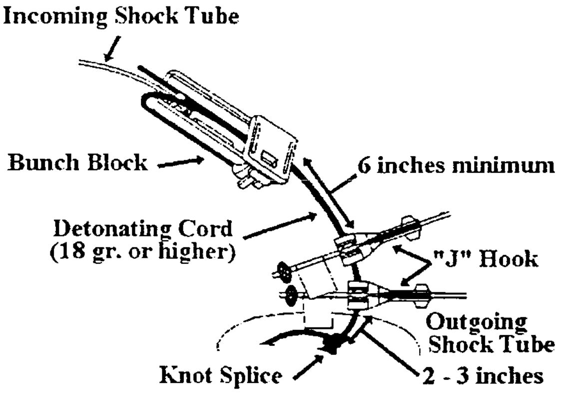


Figure 2.20

normally do not require covering. They will not reliably initiate detonating cord.

Shock tube initiation systems are manufactured in various lengths. Proper length units must be ordered. Do not splice or stretch units that are too short, as this practice may result in misfires. If the existing unit is too short, obtain a longer length unit or connect two units together in series. Shock tube should not be cut and the tube left open as this may cause a malfunction due to moisture or loss of ignition dust.

ACCESSORIES

Non-electric initiation systems are started with some sort of heat and/or shock producing device. Fuse and cap system normally utilizes a hotwire lighter. Detonating cord systems uses a cap and fuse, an electric detonator or a non-electric detonator attached parallel to the detonating cord and facing in the direction of the path of initiation. Low energy detonating cord systems use the same initiation as detonating cord but require a Detaline® starter to transfer the energy from the initiator to the cord. The shock tube system may use the same initiation as the detonating cord system, use detonating cord itself, or may use either an electric or non-electric (shotgun primer) shock tube starter (Figure 2.21).

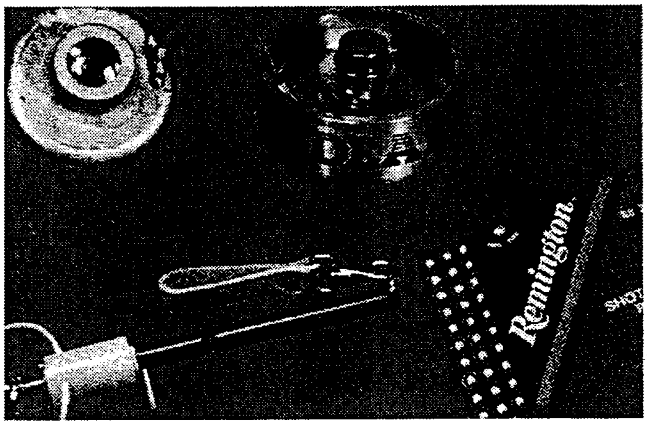


Figure 2.21

When preparing the lead-in line for a blast, it should be spooled out by walking. Detonating cord, low energy detonating cord or shock tube can potentially be damaged or even prematurely detonate if a snag develops while spooling from the back of a vehicle. The initiation devices should not be connected to the lead line until after the blast is loaded, the blast area cleared and guarded and the blast is ready to be detonated.

BLASTER'S NOTES

CHAPTER 3

BLAST DESIGN

In mining and construction, blasting is critical to the overall success of the operation. A good blasting program contains two fundamental blaster responsibilities: planning and paying attention to details during loading and blast detonation. This chapter will cover the planning phase and the latter is covered in Chapter #6. Blast design and planning should be focused in four general categories:

MASS: The rock properties and effects of geology
ENERGY: The explosives, their physical properties, quantity, and geometric distribution in the rock mass
TIMING: The sequential release of the explosive energy
COST: The cost of the blasting to the bottom line of the operation

ROCK PROPERTIES AND GEOLOGY

Blasters, with experience, developed a certain "feel" of how a rock mass will react to different explosives and pattern designs. Regulations require one year of hands-on blasting experience prior to obtaining certification. Because blasting can be more an art than a science, the apprentice period is necessary to insure a blaster develops this "feel".

A knowledge of rocks, their physical characteristics, and their geological structure is essential in blast design. After initial blasts, result data can be analyzed and used to produce optimum designs for drill patterns and explosives.

Rock properties often vary from one part of an operation to another. The blaster should develop a map characterizing the rock lithology in the operation. He may wish to seek the help of a geologist and his drillers in performing this task. Most data will be obtained from the rock surface, especially the open face of a blast bench. Jointing is probably the most prevalent geologic feature of the rock. The direction, severity and spacing between the joint sets should be documented. In most sedimentary rocks there are at least three joint sets, one dominant and two less severe. The strike and dip of bedding planes should also be noted. The presence of major zones of weakness (Figure 3.1), such as faults, open beds, mud seams,

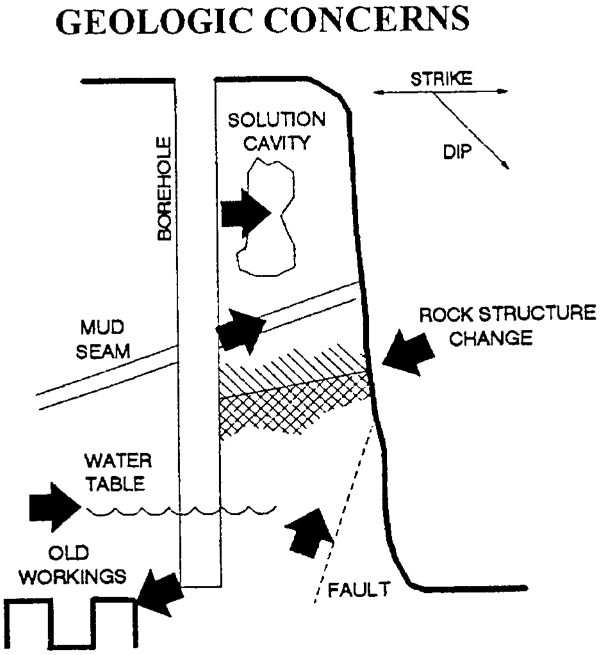


Figure 3.1

solution cavities, incompetent rock, unconsolidated material, and old mine workings should also be determined. If core drilling has been performed, that data collected on type, hardness, density, and lithology can be helpful in blast design.

An observant driller can help in assessing rock variations in a particular blast bench. Slow penetration, vibration and excessive drill noise indicate hard rock that will he difficult to break. Fast penetration and a quiet drill indicate softer rock. No resistance, drill cuttings or return air or water indicate a void. Lack of cuttings or return water may also indicate an open bedding plane or other crack. Changes in the color or nature of the drill cuttings indicate the location of various beds in the formation. A detailed drill log (Figure 3.2) should be kept by the driller and provided to the blaster to assist in blast design.

DRILLER'S LOG

HOLE No.	HOLE DEPTH	LOOSE MAT'L	COLLAR TUBE	CRACKS SEAMS	SOLUT'N CAVITY	MUD	WATER
1	52	0 12	13	32		-	7
2	52	0-4	5	-	35 - 39	-	32
3	51	-	-	-	-	14	1

Figure 3.2

Most rocks are made up of two or more minerals, although pure sandstone contains only quartz. There are three main classes of rocks with many types within each class. Igneous (cooled magma), sedimentary (pre-existing rocks, sediments, solution and organic material subjected to heat, pressure and chemical action in massive beds or layers), and metamorphic (igneous and sedimentary rocks subjected to heat, pressure and chemical action--creating changes). Common examples of sedimentary rocks are coal, sandstone, limestone, and shale. Granite and basalt are igneous rocks. Quartzite, slate, and marble are metamorphic rocks.

Sedimentary rocks are more common in surface coal mine blasting and present a wide variation of blasting problems. The integrity of the rock is affected by seams, cracks, joints and voids. These conditions, coupled with excessive burden, toe and backbreak, present the blaster with most of his problems. Quarry and construction blasting may encounter any of the three rock groups. Blasting techniques may vary widely.

There are several rock properties that are useful in blasting calculations. Probably the most widely used is rock density. Rock density is a measure of its weight per unit volume, usually given in g/cc, lbs/cu. ft., or tons/cu.yd. Typical values range from about 1.7 g/cc for chalk to about 3.6 for taconite. Specific types of rock may also vary in rock properties. As an example, a West Virginia sandstone may have a density of 2.5 gm/cc, where an Arizona sandstone may have a density of only 1.9 gm/cc. Bituminous coal ranges from about 1.2 to 1.5 gm/cc. To convert gm/cc to lb/cu.ft., multiply by 62.43. To convert lb/cu.ft. to lb/cu.yd., multiply by 27. To convert lb/cu.yd. to tons/cu.yd divide by 2000. Rock densities may be required for powder factor (discussed later in this chapter) and ore reserve calculations.

Two rock properties that are sometimes required in detailed blast design calculations are Young's Modulus and Poisson's Ratio. Young's Modulus is the ratio of normal stress to normal strain for a material under a given load condition. Poisson's Ratio is the ratio of transverse normal strain to the longitudinal normal strain of a body under a uniaxial stress. These numbers are required in blast design above what is covered in this study guide. A blaster interested in pursuing higher level blast design for specialized fragmentation and computer simulation should utilize the references in Appendix H or others available.

The compressive strength of common rock types varies from about 10,000 psi to 46,000 psi.

Some typical values are a West Virginia shale, 11,600 psi; a West Virginia sandstone, 19,400 psi; a West Virginia limestone, 23,000 psi; and a New York basalt, 46,600 psi. Rock breaks in tension, not in compression, and most rocks have a compressive strength value that is eight (8) to ten (10) times the tensile strength. The rock strength, abrasiveness, and hardness are of interest because of their effect on drilling speed and wear, as well as operating costs. However, these properties are not reliable indicators of blasting or loading methods. For example, sometimes a softer, more resilient rock that drills easily (like dolomite) may require more blasting energy than a harder, more brittle type (like granite), which is more difficult and costly to drill. Rocks are classified into four groups: very hard (like iron ores), hard (granite, quartzite), medium (dolomite, some limestones and some sandstones) and soft (shales, some sandstones and some limestones). In blasting, soft rock is more "forgiving" than hard rock. If soft rock is underblasted, it can still be excavated. If it is slightly overblasted, the excessive violence may be absorbed by the rock. However, slight underblasting of hard rock often causes a tight muck pile which is difficult to excavate and overblasting may cause excessive flyrock and airblast. Therefore, blast designs for hard rock require closer control and better design than those for soft rock. Table 3.A shows the generic properties of many rocks.

Voids and zones of weakness such as solution cavities, underground workings, mud seams and faults may create serious problems for blasters. Explosive energy seeks the path of least resistance, and when vented results in poor fragmentation. Other possible undesirable effects are excessive flyrock and airblast. If the blasthole intersects a void zone, care must be taken to avoid loading excess explosive into the void area, producing a high concentration of explosive energy in a marginally confined area. The blaster should attempt to plot the trends of faults and mud seams. A good drill log, documenting voids and weak zones, is essential. When loading the hole, inert stemming material should be loaded through these zones. This will result in better energy utilization and reduce the chances of unwanted effects such as flyrock and airblast.

Rock properties can change within a given shot. This is especially true in sedimentary rock such as found in coal mining. Alternate zones of competent and incompetent rock may be layered which can result in blocky fragmentation. If this is a problem you may need to shorten the timing delays in the shot allowing less energy venting, or use smaller diameter blastholes, closer together, to get a better explosive distribution. Stemming material should be used in open beds and zones of extremely soft or weak rock. and a deck charge or satellite hole may be required in hard cap rock (Figure 3.3). Where prominent bedding planes exist, the blaster may adjust the drill depth and face height to obtain good breakage at the toe without utilizing the expense of subdrilling. This is especially true in quarries and on breakdown benchs in surface coal operations.

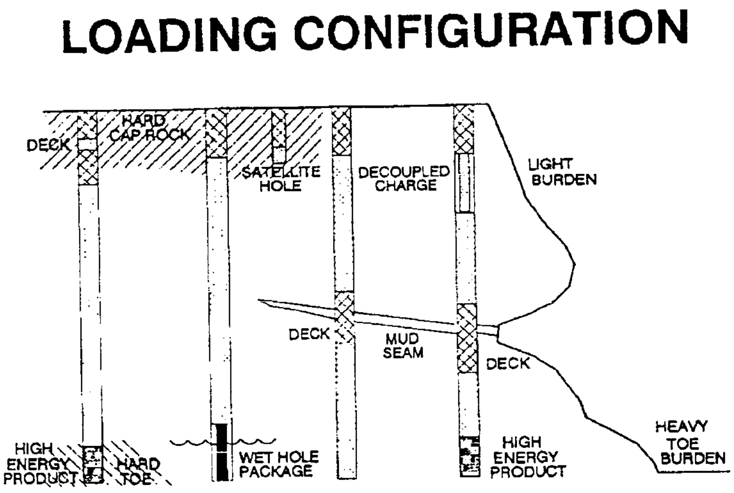


Figure 3.3

TABLE 3.A - ROCK PROPERTIES

ROCK TYPE	YOUNG'S MODULUS KBARS	POISSON'S RATIO	BULK DENSITY gm/cc	TENSILE STRENGTH psi	COMPRESS STRENGTH psi	TONS per CU.YD
Anorthosite	659	0.22	2.6	1680	34871	2.19
Asbestos	670	0.2	2.7	740	13275	2.28
Basalt	623	0.28	2.9	1552	21630	2.44
Basalt	1005	0.28	3.0	2290	42349	2.57
Chalk	53	0.39	1.7	132	2169	1.43
Coal - Anthrosite	-	-	1.6	-	-	1.35
Coal - Bituminous	-	-	1.3	-	-	1.10
Diabase	427	0.10	2.8	1890	10264	2.36
Diorite	715	0.17	2.9	2090	11789	2.44
Dolomite	282	0.33	2.5	366	7943	2.11
Dolomite	404	0.34	2.5	506	11796	2.11
Feldspar	452	0.18	2.6	1250	18960	2.19
Gabbro	1010	0.34	3.1	1305	29047	2.61
Granite	190	0.38	2.6	854	19710	2.19
Granite	601	0.25	2.7	1688	31415	2.28
Granite	810	0.22	2.8	1985	32351	2.36
Greenstone	811	0.3	3.0	1612	16366	2.52
Limestone	179	0.33	2.3	322	5111	1.94
Limestone	565	0.21	2.6	827	19519	2.19
Limestone	811	0.27	2.8	1340	26022	2.36
Marble	1061	0.28	3.0	2206	36400	2.52
Norite	1010	0.27	2.9	1800	26719	2.44
Peridotite	1096	0.29	3.3	1000	17750	2.78
Potash	75	0.36	1.9	675	5250	1.60
Quartz	423	0.24	2.6	1518	31167	2.19
Quartz	626	0.24	2.6	2530	45172	2.19
Rhyolite	357	0.25	2.5	987	13172	2.11
Sandstone	59	0.31	1.9	40	1540	1.60
Sandstone	47	0.26	1.9	86	4334	1.60
Sandstone	43	0.4	2.2	165	5925	1.85
Schist	694	0.27	2.7	1273	20625	2.28
Schist	768	0.20	2.9	1330	24010	2.44
Serpentine	532	0.33	2.8	740	16351	2.35
Shale	210	0.32	2.4	1756	17256	2.02
Shale	434	0.27	2.7	2100	26956	2.28
Slate	659	0.17	2.6	927	12390	2.19
Slate	713	0.23	2.7	1518	24989	2.28
Syenite	756	0.26	2.7	1582	24989	2.28
Taconite	616	0.33	3.6	2317	44201	3.03
Taconite	929	0.25	3.0	2474	36401	2.53

Jointing can affect both fragmentation and highwall or stability. Close jointing usually gives good fragmentation while wide jointing often results in a blocky muck pile. The best solution in wide jointing may be smaller blastholes closer together. The extra drilling and loading cost can often be offset by the savings in loading, hauling, crushing, secondary blasting and maintenance. Where possible, the perimeter holes of a blast should be aligned with the principal joint sets for increased highwall stability. Rows of holes diagonal to a principal joint set may produce ragged, unstable highwall conditions.

Because of tectonic movement, some previously horizontal bedded rock now finds its bedding plains on a slope. The angle of incline from horizontal is called the Dip. The main horizontal course or direction of a mineral deposit and perpendicular to the Dip is the Strike (Figure 3.4). In blasting with the dip, the blaster may expect more backbreak, a smoother pit floor, better utilization of the explosive energy, less toe problems, more movement away from the face and a lower muck pile profile. The major concern is highwall stability where bedding plain interfaces may fail resulting in extremely unsafe working conditions. In blasting against the dip, expect less backbreak, some toe problems, rougher floor conditions, less movement from the face, and a higher muck pile. In blasting against the strike, expect nominal fragmentation, an uneven floor, a stable high wall with some "spotty" backbreak conditions, and nominal displacement.

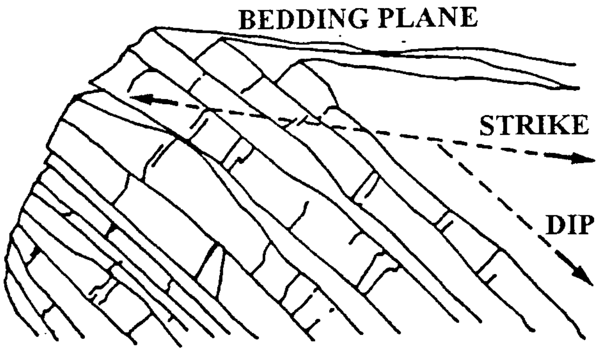


Figure 3.4

Geology plays a major determining factor in blast design. As geological conditions change, adjustments to the company blast plan should be considered, in order to use the geology to its best advantage. Geology is a factor in determining borehole diameter, hole depth, bench height, pattern geometry, loading configuration, and delay timing sequence. Tight corners (90° or less) should be avoided (Figure 3.5). Explosive energy will normally break through these corners (A) causing instability and large boulders. Where the bench ends (B), corner holes should be timed to provide adequate relief. Normal blast benches should utilize corners greater than 90° (C) to insure stable highwalls. Where possible (D) blast patterns should conforming to the geological structure.

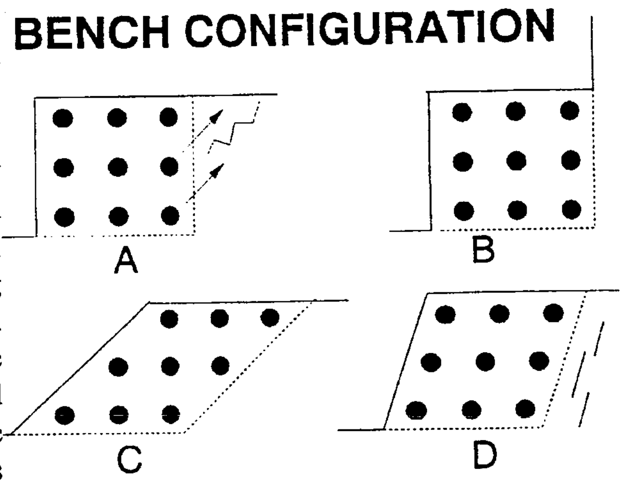


Figure 3.5

BENCH CALCULATIONS

Explosive energy is the primary force in blasting. Proper control and utilization of this energy is paramount. To accomplish this, the blaster must keep three principle factors in balance:

1. Explosive energy - There must be sufficient energy available to break the rock mass. This

may be accomplished using a powder factor calculation which is discussed in detail later in this chapter. Failure to provide sufficient energy may result in poor fragmentation, minimal displacement, hard digging, and high vibration. Excessive energy may result in lack of control, flyrock and airblast.

2. Explosive distribution - The explosive charge must be properly distributed within the rock mass to provide uniform fragmentation. This is accomplished with proper hole diameter, drill pattern and hole placement, loading configuration, and delay timing. Failure to provide good energy distribution may result in poor fragmentation, hard digging, vibration, airblast, flyrock, misfires, and unstable highwalls.

3. Explosive confinement - The explosive charge must be properly confined to optimize its work potential. This is accomplished through proper stemming, hole placement, primer location, loading configuration, and timing. Failure to provide proper energy confinement may result in poor fragmentation, high bottom, minimal displacement, high vibration, airblast, flyrock, and misfires.

Each factor above compliments the other two. If one is neglected, the other two will suffer and poor blast performance will result. The important role of geology must be considered when implementing these three design factors.

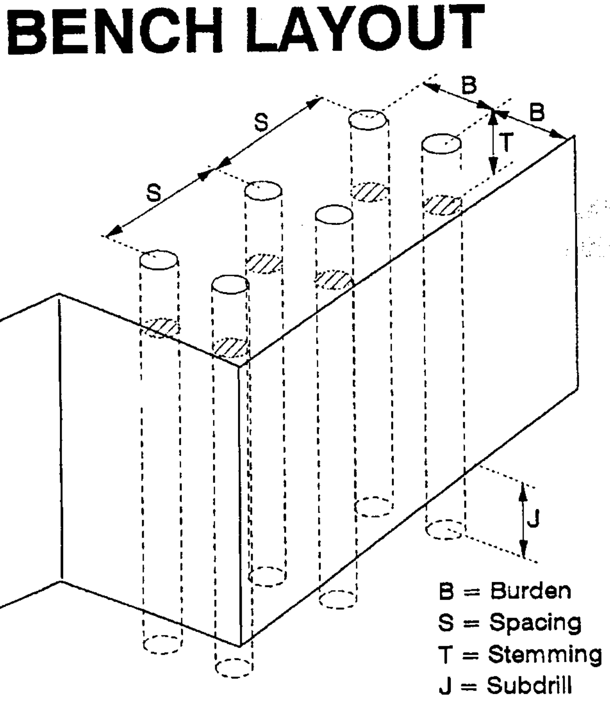


Figure 3.6

The blaster must consider a number of measured dimensions when planning a blast (Figures 3.6). The figure represents typical conditions in surface mining applications, a near vertical highwall and vertical boreholes. Sometimes angled holes are drilled to handle heavy toe burdens or to assist in material displacement (cast blasting). If angled holes are utilized, the angle of incline is from the vertical position (0°). The blaster should familiarize himself with the universal blasting terms that follow. To be a blaster you must speak the language.

Bench Height (BH) - The desired cut depth of rock mass to be blasted and excavated. In normal open pit operations it is equivalent to the height of the open face of the blast bench. The bench height is determined by geology, quantity of overburden, safety considerations, or regulatory requirements. In surface coal mining operations, the overburden, which is the rock and earth material above the coal seam, usually dictates the bench height. It is normally an integer (whole number) multiple of the overburden depth. In quarrying, overburden, drill capabilities, and safety determine bench height.

Borehole diameter (d) - The diameter of the drilled hole in inches, usually taken as the bit diameter used to drill the hole. This diameter, the type of explosive used and the type of rock to be blasted are factors in determining the burden. The borehole diameter is an important variable and is usually determined by the drilling equipment on hand and the proposed bench height, thus the blaster normally has little freedom in the choice of borehole diameter selection. Practical diameters for surface mining range up to about 18 inches. Larger diameters holes result in larger patterns and normally yield lower costs since drill footage per bank cubic yard is less. In most cases fragmentation will suffer since energy distribution is compromised. Large holes on large patterns are usually found in high volume operations which employ loading, hauling and processing equipment capable of handling the coarser fragmentation. Vibration and airblast are also constraint considerations for using large diameter boreholes. For best fragmentation and design control, the rule-of-thumb is that the borehole diameter is about one tenth of the bench height (or overburden).

Equation 3.1: $d = BH / 10$

where d = Borehole Diameter (inches)

BH = Bench Height (feet)

Burden (B) - Burden is expressed in two ways, measured burden and true burden. Measured burden (Figure 3.6) is the distance from the first row of holes to the open face or the distance between rows of holes. True burden is the distance from the center of the bottom of the borehole to the nearest free face at the instant of detonation. This nearest free face can change as a function of the sequence of hole initiation. For example (Figure 3.7), the holes are drilled in a square pattern, but firing in an echelon sequence changes the actual burden on the blast hole. As a rule of thumb, the measured burden can be calculated as a function of the borehole diameter and a constant based on the type of explosive used.

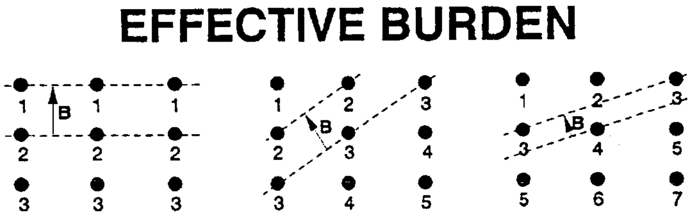


Figure 3.7

Equation 3.2: $B = d_e \times K$

where B = Burden (feet)

d_e = explosive column diameter (inches)

K = explosive constant

$K = 2$ for ANFO in average rock

$K = 2.5$ for dynamite, water gels, etc. in average rock

Spacing (S) - The distance between adjacent boreholes measured perpendicular to the burden (Figure 3.6). As a rule of thumb, the spacing is 1 to 2 times the burden dimension. The typical multiplier used for a rectangular pattern is 1.2. The actual multiplier depends on the geology and the delay timing to be used. In areas of heavy burden, especially on the front row where toe burdens may be excessive due to backbreak, reduced spacings (less than the burden dimension) may be required.

Equation 3.3: $S = B \times K$

where S = Spacing (feet)
B = Burden (feet)
K = constant from 1 to 2 (typical 1.2)

Blast Pattern - The blast pattern is the geometric arrangement of boreholes (burden and spacing) required to provide proper energy distribution in the rock mass. There are three basic blast patterns used (Figure 3.8). The square pattern has the burden and spacing dimensions equal. The rectangular pattern has the burden dimension less than the spacing dimension. The staggered pattern has the burden dimension less than or equal to the spacing dimension with the holes in subsequent rows offset by half the spacing dimension. The type of blast pattern used is a function of the geological structure and its orientation to the blast bench and the delay timing sequence to be used.

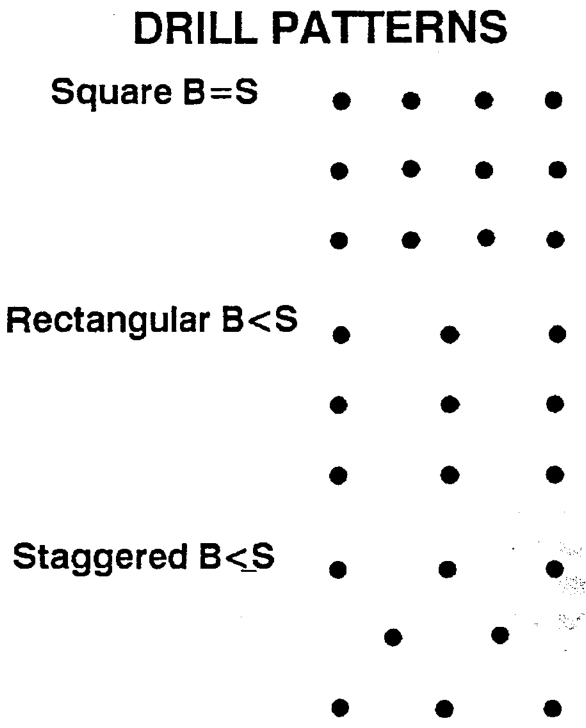


Figure 3.8

Hole depth (H) - Distance from top of ground to bottom of borehole. To provide good fragmentation the bench height to burden ratio (called the stiffness ratio - SR) should be a number greater than 2. If the ratio is less than 2 energy distribution is compromised and fragmentation and control will suffer. For shorter benches use a smaller borehole diameter. The upper limit of the height to burden ratio is established at about 4 because of the concern for borehole deviation during drilling. If accurate drilling is possible, there are no adverse affects in exceeding the ratio of 4.

Equation 3.4: $H = B \times SR$

where H = Hole depth (feet)
B = Burden (feet)
SR = constant from 2 to 4 (typical 2.6)

Subdrilling (J) - The distance drilled below the desired cut elevation to insure that the rock can be excavated to grade (Figure 3.6). Subdrilling is not used in surface coal mining. It is common in quarry and construction operations where a natural seam does not exist at the cut elevation. In operations where excessive toe exists, additional subdrilling may be required on the front row holes. Excessive subdrilling may increase vibration levels. Subdrilling is a function of the burden and an empirical constant which is a function of the geology. This constant ranges between 0.2 and 0.5. The typical value used is 0.3.

Equation 3.5: $J = B \times K$

where J = Subdrilling (feet)
B = Burden (feet)
K = Empirical constant from 0.2 to 0.5 (typical 0.3)

Stemming Height (T) - Distance from the collar of the borehole to the top of the explosive column (Figure 3.6). This volume is filled with an inert material, usually drill cuttings or angular gravel to provide confinement of the explosive energy and reduce flyrock and airblast. In water filled holes, angular gravel is recommended. Use of drill cuttings in this situation may cause water density to increase and allow explosive column separation. Stemming height is a function of the burden and empirical constant based on the geology , the amount of broken material on the bench surface, and the blaster's experience.

Equation 3.6: $T = B \times K$

where T = Stemming Height (feet)
B = Burden (feet)
K = Empirical constant from 0.5 to 1.3 (typical 0.7)

Decking Length (Y) - The length of explosive charge in a decked borehole. A decked borehole is a hole containing two or more separate explosive charges separated by inert stemming material. Decking is used to avoid loading explosives into soft or broken seams, to reduce vibration levels by limiting the amount of explosives per delay period, or to provide better energy distribution in the blasthole such as in cap rock. The length of the decked explosive charge is dependent on the reason for decking. Each deck may be detonated at a separate delay interval or all decks can be detonated on the same delay. In most cases it is a judgement call by the blaster. If the decking is required because of charge weight constraints due to vibration, then the blaster must first determine the allowable charge weight per delay (W) using the Scale Distance Formula (Equation 5.1) in Chapter #5. The length of the charge is a function of the allowable charge weight, the charge diameter, and the charge density. The actual charge length may be reduced to equalize the deck charges and allow for stemming between decks.

Equation 3.7 $Y = W / (0.3405 \times \rho \times d_e^2)$

where Y = Maximum decking length (feet)
W = Charge weight (pounds) = $(D / SD)^2$
ρ = Explosive density (gm / cc)
d_e = explosive column diameter (inches)

Deck Stemming Length (Z) - The minimum recommended length of stemming to be used between decks. The minimum length is a function of the borehole diameter, the type of stemming material and the conditions of the borehole. The minimum deck length in feet using angular gravel stemming in a dry borehole is about 0.5 times the borehole diameter in inches. This length should be doubled in wet holes due to potential dead pressing caused by the shock transmission through water.

Equation 3.8 $Z = d \times 0.5$

where Z = minimum deck stemming length (feet)
d = hole diameter (inches)

Explosive Column (EC) - The length of the explosive charge in the borehole. The explosive column length is a function of the hole depth less the collar stemming and deck stemming lengths.

Equation 3.9: $EC = H - T - Z$

where EC = Explosive Column (feet)
H = Hole Depth (feet)
T = Collar Stemming (feet)
Z = Deck Stemming (feet) *sum of deck stemming if more than one*

The explosive column length (EC) may be divided into equal charge lengths if multiple decks are required for limiting vibration. The resulting lengths can then be compared to the maximum charge length calculated by Equation 3.7 to determine if additional decks are required.

Explosive Column Weight (W) - The total explosive column weight per borehole is a function of the explosive density, its diameter, and the explosive column length (EC).

Equation 3.10: $W = 0.3405 \times \rho \times d_e^2 \times EC$

where W = Explosive charge weight (pounds)
ρ = explosive density (g/cc)
d_e = explosive diameter (inches)
EC = explosive column length (feet)

Example Problem:

Determine the charge weight of a 6 inch diameter borehole, loaded with a 40 feet column of bulk ANFO with a loading density of .85 g/cc.

$W = .3405 \times 0.85 \times (6)^2 \times 40 = 416.8$ lbs per hole

Many explosive suppliers provide Blaster's guides, which contain loading density charts similar to Table 3.B. The loading chart uses Equation 3.10 to calculate its values. The row across the top of the table contains the density of the explosive (ρ) in gm/cc. The column on the left side of the table contains the explosive diameter (d_e in inches). The value of 1 is assigned to the explosive column length, such that the values determined by the table are in pounds per foot of borehole. To determine the pounds of explosive loaded in a borehole using Table 3.B, first locate the explosive density in the row across the top of the table. Second locate the explosive diameter in the column at the left of the table. The number located at the intersection of the density column and the diameter row represents the loading density of the borehole in pounds per foot. To determine the number of pounds of explosive in the borehole, multiply the table loading density by the explosive column height (Equation 3.9)

TABLE 3.B - LOADING DENSITY CHART

Pounds per foot of column for given Densities (g/cc)																	
Dia."	0.80	0.82	0.85	0.90	0.95	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.60
1½	0.61	0.63	0.65	0.69	0.73	0.77	0.80	0.84	0.88	0.92	0.96	1.00	1.03	1.07	1.11	1.15	1.23
2	1.09	1.12	1.16	1.23	1.29	1.36	1.43	1.50	1.57	1.63	1.70	1.77	1.84	1.91	1.97	2.04	2.18
2½	1.70	1.75	1.81	1.92	2.02	2.13	2.23	2.34	2.45	2.55	2.66	2.77	2.87	2.98	3.09	3.19	3.41
3	2.45	2.51	2.60	2.76	2.91	3.06	3.22	3.37	3.52	3.68	3.83	3.98	4.14	4.29	4.44	4.60	4.90
3½	3.34	3.42	3.55	3.75	3.96	4.17	4.38	4.59	4.80	5.01	5.21	5.42	5.63	5.84	6.05	6.26	6.67
4	4.36	4.47	4.63	4.90	5.18	5.45	5.72	5.99	6.27	6.54	6.81	7.08	7.35	7.63	7.90	8.17	8.72
4½	5.52	5.65	5.86	6.21	6.55	6.90	7.24	7.58	7.93	8.27	8.62	8.96	9.31	9.65	10.00	10.34	11.03
5	6.81	6.98	7.24	7.66	8.09	8.51	8.94	9.36	9.79	10.22	10.64	11.07	11.49	11.92	12.34	12.77	13.62
5½	8.24	8.45	8.76	9.27	9.79	10.30	10.82	11.33	11.85	12.36	12.88	13.39	13.91	14.42	14.94	15.45	16.48
6	9.81	10.05	10.42	11.03	11.65	12.26	12.87	13.48	14.10	14.71	15.32	15.94	16.55	17.16	17.77	18.39	19.61
6¼	10.64	10.91	11.31	11.97	12.64	13.30	13.97	14.63	15.30	15.96	16.63	17.29	17.96	18.62	19.29	19.95	21.28
6½	11.51	11.80	12.23	12.95	13.67	14.39	15.11	15.82	16.54	17.26	17.98	18.70	19.42	20.14	20.86	21.58	23.02
6¾	12.41	12.72	13.19	13.96	14.74	15.51	16.29	17.07	17.84	18.62	19.39	20.17	20.94	21.72	22.50	23.27	24.82
7	13.35	13.68	14.18	15.02	15.85	16.68	17.52	18.35	19.19	20.02	20.86	21.69	22.52	23.36	24.19	25.03	26.70
7⅜	14.82	15.19	15.74	16.67	17.59	18.52	19.45	20.37	21.30	22.22	23.15	24.08	25.00	25.93	26.85	27.78	29.63
7⅞	16.89	17.32	17.95	19.00	20.06	21.12	22.17	23.23	24.28	25.34	26.40	27.45	28.51	29.56	30.62	31.67	33.79
8	17.43	17.87	18.52	19.61	20.70	21.79	22.88	23.97	25.06	26.15	27.24	28.33	29.42	30.51	31.60	32.69	34.87
8½	19.68	20.17	20.91	22.14	23.37	24.60	25.83	27.06	28.29	29.52	30.75	31.98	33.21	34.44	35.67	36.90	39.36
9	22.06	22.62	23.44	24.82	26.20	27.58	28.96	30.34	31.72	33.10	34.48	35.85	37.23	38.61	39.99	41.37	44.13
10	27.24	27.92	28.94	30.65	32.35	34.05	35.75	37.46	39.16	40.86	42.56	44.27	45.97	47.67	49.37	51.08	54.48
10⅝	30.75	31.52	32.67	34.60	36.52	38.44	40.36	42.28	44.21	46.13	48.05	49.97	51.89	53.81	55.74	57.66	61.50
12	39.23	40.21	41.68	44.13	46.58	49.03	51.48	53.94	56.39	58.84	61.29	63.74	66.19	68.64	71.10	73.55	78.45
15	61.29	62.82	65.12	68.95	72.78	76.61	80.44	84.27	88.10	91.94	95.77	99.60	103.43	107.26	111.09	114.92	122.58
17½	83.42	85.51	88.64	93.85	99.06	104.28	109.49	114.71	119.92	125.13	130.35	135.56	140.78	145.99	151.20	156.42	166.85

Example Problem:
Determine the charge weight of a 6 inch diameter borehole, loaded with a 40 feet column of bulk ANFO WITH a loading density of .85 g/cc.

On Table 3.B, locate 0.85 in the top row. Next locate 6 in the left column. The intersection of the density column and diameter row contains the loading density of 10.42 pounds per foot. Multiplying this value by the column height of 40 feet, we determine the borehole contains 416.8 pounds of explosive. Note, this is the same result as the calculation done on the example problem demonstrating Equation 3.10

The blaster quite often finds water in the borehole and needs to know the amount of packaged wethole explosive required to load out of the water. Equation 3.11 estimates the water volume in the hole based on the initial water height and hole diameter, and then estimates the final height of the water based on the initial volume and the calculated volume of the annulus between the borehole wall and the explosive package.

Equation 3.11: $$H_f = \frac{H_o \ x \ d^2}{d^2 - d_e^2}$$

where H_f = final height of water (feet)
H_o = Original height of water (feet)
d = borehole diameter (inches)
d_e = explosive cartridge diameter (inches)

Example Problem:
A 60 foot 8 inch diameter hole containing 10 feet of water is to be loaded with 6 inch diameter packaged explosives. Determine the column height at which the explosive will be above the final water level.

$H_f = (10) \times (8)^2 / (8^2 - 6^2) = 22.9$ feet

The explosive distribution could be 23 feet of water resistant packaged explosive (to get out of the water) and with the remaining explosive column loaded with bulk ANFO.

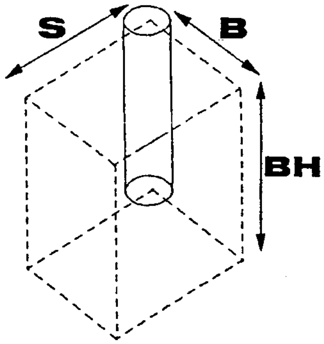


Figure 3.9

Mass Volume - The volume of material blasted. The mass volume may be expressed in terms of cubic yards (BCY) or tons (TN). In surface coal mining and construction, volume is normally expressed in cubic yards. Quarry operations normally express volume in tons, since their pay basis is in tons of rock. Volume for blasting is estimated by determining the rock mass effected by one blast hole (Figure 3.9). Since the pattern geometry is based on the energy distribution of a blast hole, the volume effected by a blast hole would be a function of the burden, spacing and bench height (Equation 3.12). If the volume is to be expressed in tons, then the results calculated for BCY must be multiplied by the appropriate rock density from Table 3.A (Tons/cu.yd.).

Equation 3.12 $$BCY = \frac{BxSxH}{27} x N$$

where BCY = Bank Cubic Yrds
B = Burden (feet)
S = Spacing (feet)
H = Bench height (feet)
N = Number of holes in blast

Equation 3.13 TN = BCY x Rock Density

Example Problem:

Determine the cubic yards in a blast containing 30 holes on a 40 foot high bench . The holes are drilled on a pattern with a 14 foot burden and 16 foot spacing. Also determine the number of tons in the blast in the rock has a density of 2.0 tons per cubic yard.

BCY = (14 x 16 x 40 / 27) x 30 = 9955.6 cubic yards

TN = 9955.6 x 2.0 = 19,911.1 tons

Powder Factor (PF) - The relationship between a quantity of explosive and a quantity of rock. There are four common ways that are used to express Powder Factor:

1. pounds of explosive per cubic yard of rock (lbs/yd^3)
2. pounds of explosive per ton of rock (lbs/ton)
3. tons of rock per pound of explosive (tons/lb)
4. cubic yards of rock per pound of explosive (yd^3/lb)

Coal and construction commonly use lbs/yd^3 for powder factor. Quarry blasting normally uses tons/lb. Powder factors for surface blasting in coal can vary from .25 to 2.5 lbs/yd^3, with 0.8 to 1.2 lbs/yd^3 being most typical. Conditions that effect the powder factor used are rock hardness, explosive energy, type of equipment used for excavation and processing, the type of blasting being done (conventional or cast blasting), and the natural relief for the blast bench (zero, one, two or three open faces). Most blasters tend to "overshoot" to insure good rock fragmentation and excavation. Equation 3.14 calculates the powder factor in pounds of explosive per bank cubic yard.

Equation 3.14: $$PF = \frac{.3405 \ x \ \rho \ x \ d_e^2 \ x \ EC}{B \ x \ S \ x \ BH \ / \ 27}$$

where PF powder factor (lb/yd^3)
ρ = explosive density (g/cc)
d_e = charge diameter (inches)
EC = explosive column (feet)
B = burden (feet)
S = spacing (feet)
BH = bench height (feet)

You will note that the powder factor equation is Equation 3.10 divided by Equation 3.12 figured for one hole (N = 1). In actual bench blasting where bulk blasting agents are used, the blaster may figure the powder factor by dividing the total amount of explosives used (by weighing the truck) by the total bench mass (BCY for one hole times the number of holes)

Example Problem:

Determine the quantity (lbs) of ANFO at a density of .80 gm/cc used, the volume of rock blasted (yds^3), and the powder factor (lb/yd^3) for a blast with the dimensions listed below. No subdrilling was used in this blast.

Burden = 12 feet	Diameter = 6 inches
Spacing = 15 feet	Stemming = 8 feet
Bench Height = 30 feet	Number of holes = 12

$W = 0.3405 \times 0.8 \times 6^2 \times (30 - 8) \times 12 = 2588.9$ lbs of ANFO

$CY = (12 \times 15 \times 30 / 27) \times 12 = 2400$ cubic yards blasted

$PF = 2588.9 / 2400 = 1.08$ lbs/yd

The equations above are general accepted rules for blast design, however in the real world of blasting, experience is the best instrument. This is especially true in designing the front row of holes. Backbreak and backshatter from the previous shot usually results in an open face with various structures and burdens. Care must be taken in blasthole location and explosive loading. Where burdens vary, customized drill patterns and hole loading are a must to insure good fragmentation without flyrock and airblast. Front row spacing may vary based on the burden in front of each respective hole (Figure 3.10). Once holes are drilled, the burden over the entire length of each hole should be determined. Based on the burden at each location along its length, the hole should be custom loaded to provide uniform

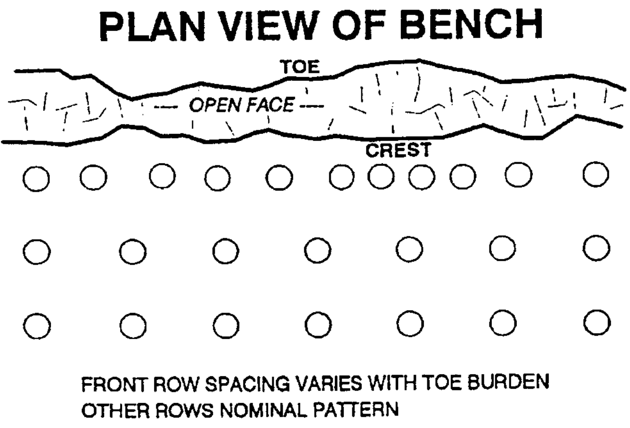


Figure 3.10

explosive to rock mass ratio. This can be accomplished by using explosives of different density or energy, using explosives of different diameter, or by decking through areas of concern (Figure 3.11).

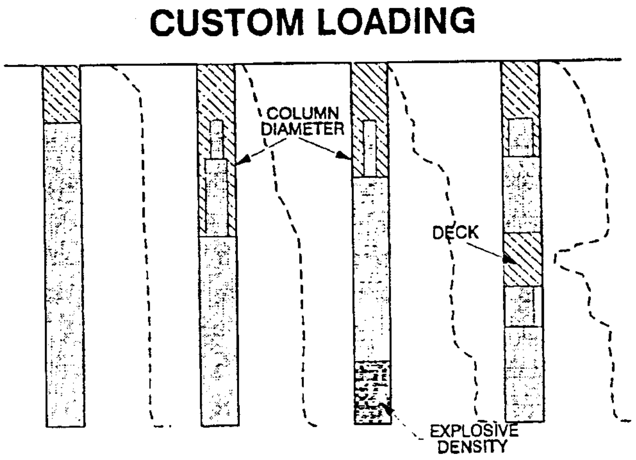


Figure 3.11

TIMING

With the blast bench properly designed and the explosive energy properly distributed, the next critical factor in blast design is the proper sequencing of the release of the explosive energy. This sequencing is accomplished by the initiation system. Details on delay timing are covered in Chapter #4.

COST

For any mining operation to be profitable, it must optimize its cost. A good blasting program is essential to the success of a mining operation. The cost of blasting should not be based solely on the price of the explosive purchased, nor should it be based only on the cost of the drilling and blasting operation. The cost of the blasting operation must be based on the bottom line cost of the entire operation. Often a more expensive explosive will allow expansion of drill patterns which may lower the drill and blast cost. Furthermore a slight increase in the cost of drilling and blasting may result in higher productivity, better equipment and personnel utility, lower maintenance costs, and a lower overall operating cost.

SPECIALTY DESIGNS

Not all blasting in the mining industry is open face bench blasting. Often the blaster is required to perform blasting that is non-routine. Blasting that falls into this category are presplit, cast blasting, parting shots, and sink shots. Following are some general guidelines to the specialties. A blaster of limited experience should seek advice of an experienced person in areas of specialty blasting.

PRESPLIT: Presplit or preshear is a form of controlled blasting usually performed at the perimeter of the excavation for the purpose of highwall stability. Three primary loading configurations are employed in this type of blasting, continuous decoupled string, spaced decoupled cartridge and air deck (Figure 3.12). The blasting principles of presplitting are simple. When the explosive, which is decoupled in the hole, detonates and the hot gases expand, it generates a certain amount of pressure within the confines of the borehole. This pressure must be greater than the tensile strength of the rock but less than the compressive strength. This application of pressure allows the explosive to pull a crack between the boreholes without crushing and shattering the rock. Once the presplit crack is established, it provides an interface between the production blast holes and the perimeter rock mass, terminating the blast shock, pressure and stress at the interface. Best results are obtained if all presplit holes are fired at the same time, however if delay timing is required, the delay interval should be kept to a minimum.

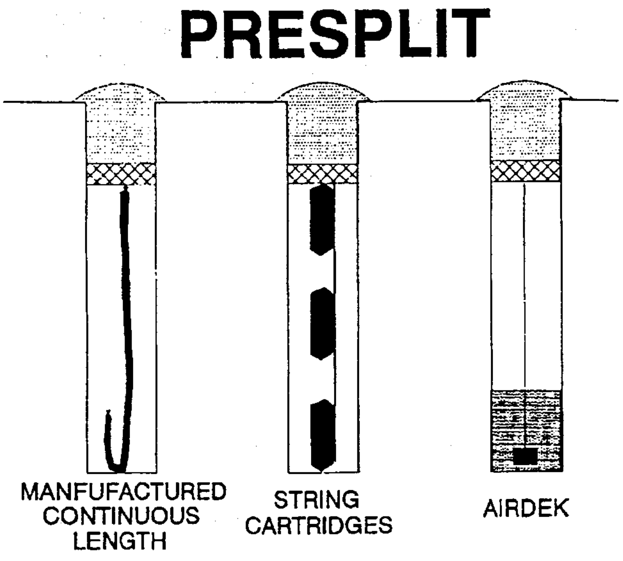


Figure 3.12

Air decking is a form of presplitting which under the right conditions can save considerably on cost. Because the explosive charge is confined at the hole bottom rather than distributed along the column length, the perimeter wall must contain competent material. It is recommended that single charge air decking not be used in holes greater than 70 feet in depth. As a rule of thumb 10% to 15% of the borehole is loaded with ANFO and the hole is plugged and stemmed at about 1.0 to 1.2 times the hole diameter in feet. Borehole spacing is about 1.5 to 2.0 times the hole diameter in feet.

Some rules of thumb for presplitting are listed in Table 3.C

TABLE 3.C PRESPLITTING RULES OF THUMB

Borehole Diameter (inches)	Explosives Load (lbs/ft)	Hole Spacing (inches)
1.5	0.08	12 to 18
2.0	0.17	18 to 24
2.5	0.23	24 to 30
3.0	0.34	24 to 36
3.5	0.50	24 to 36
4.0	0.60	36 to 48
5.0	0.90	36 to 60
6.0	1.30	48 to 72
8.0	2.00	60 to 84

CAST BLASTING: Cast blasting is the use of explosive energy to displace overburden to an adjacent location reducing the requirements of excavation. To accomplish this the amount of explosive energy is increased by raising the powder factor to from 1.2 to 1.8 lbs/yd^3. Since energy is being used to displace material, design parameters must be followed to insure blast control. Bench heights less than 40 feet may not be economical for cast blasting. The bench height to pit width ratio should be 1 to 1 and never less than 1 to 2. Timing delays between the holes in a row are less to provide uniform energy distribution pushing the rock mass. The burden on the front row of holes must be thoroughly analyzed to insure proper movement. If the first row does not move, the remaining rows have no relief. Angled holes may help in casting since they will provide a more uniform burden on the front row, they provide a longer hole and thus more explosive per hole and they elevate the rock trajectory. The important thing to remember in cast blasting is to monitor cost. The sole purpose of cast blasting is to save money. The drill and blast cost will be increased. This additional cost must be recovered through productivity, personnel and equipment utilization, maintenance, etc for the use of cast blasting to be worthwhile.

PARTING SHOTS: Parting shots are used to remove small rock layers between coal beds or other recoverable ore bodies. In most cases bench heights are very short (10 feet or less) and the techniques used for open face surface blasting will not apply. The application of crater blasting theory is normally used in parting shots. Because of the large number of variables involved, there is no simple equation to develop an optimum design. Factors to consider are explosive energy, explosive weight, blast hole diameter, type and lithology of the rock mass, the rock stress factor, burial depth, and the excavation equipment. The easiest means of shot design is by trial and error shooting one hole at a time until the proper loading design is accomplished. A proper design will result in vertical movement of the rock mass but not in a violent eruption. The control factors are the quantity and burial depth of the explosive charge. Blast patterns are dependant on geology and excavating equipment. Normally the intersection of the crater rims is sufficient to allow easy excavating. Blast timing is usually on short delay intervals to allow interaction between the cratering charges.

SINK SHOTS: Sink shots are blasts that have no open face for initial relief. This free face must be generated by the explosive, with the initial holes utilizing vertical relief to generate internal free faces in the remainder of the blast. Normally the pattern for the initial holes is smaller and has additional subdrilling to increase the powder factor and explosive energy. Additional stemming may be required on the initial holes to assist in confining the explosive energy to provide vertical displacement. The opening holes should be located where they will provide the most relief, the center of the shot on a shaft, the shorter holes on a ramp, etc. The remaining holes in the blast should conform to normal bench design utilizing the internal free face created by the opening holes. Shot timing in the opening holes should be on short time intervals with the remainder of the shot on normal intervals.

BLASTER'S NOTES

BLAST DESIGN RULES OF THUMB

HOLE DIAMETER **(d)** = hole depth **(H)** divided by 5 to 10.

d(in) = **H**(ft) / 5 to **H**(ft) /10 (Usually not an option)

BURDEN (B) = 2 to 3 times the diameter.

B(ft) = 2 X **d**(in) to 3 X **d**(in) (Typically 2.5 X d)

SPACING (S) = 1 to 2 times the burden.

S(ft) = 1 X **B**(ft) to 2 X **B**(ft) (Typically 1.5 X B)

STEMMING (T) = 0.5 to 1.0 times the burden.

T(ft) = 0.5 X **B**(ft) to 1.0 X **B**(ft) (Typically 0.7 X B)

POWDER COLUMN (PC) = hole depth minus stemming.

PC(ft) = **H**(ft) - **T**(ft)

LOADING DENSITY (LD) = 0.3405 times the explosive density times the hole diameter squared.

LD(lb/ft) = 0.3405 X **density**(gm/cc) X $\mathbf{d}^2$(in) (or Mfg design guide)

CHARGE WEIGHT (CW) = powder column times the loading density.

CW(lb) = **PC**(ft) X **LD**(lb/ft)

POWDER FACTOR (PF) = total explosives per hole divided by rock volume per hole.

PF(lb/yd^3) = **CW**(lb) / [**B**(ft) X **S**(ft) X **H**(ft) / 27]

SCALED DISTANCE (SD) = Distance to structure divided by square root of the weight per delay.

SD(ft/lb) = **distance**(ft) / $\sqrt{\mathbf{W}}$ (lbs/delay) (SD, Should be greater than 55)

PEAK PARTICLE VELOCITY (PPV) = 438 times scaled distance to the -1.52 power.

PPV(in/s) = 438 X $(\mathbf{SD})^{-1.52}$ (OSM, maximum expected)

PPV(in/s) = 160 X $(\mathbf{SD})^{-1.60}$ (USBM, average expected)

$$\text{PPV(in/s)} = 160 \text{ X } \left(\frac{\mathbf{dis\,tan\,ce}}{\sqrt{\mathbf{W}}}\right)^{-1.6}$$

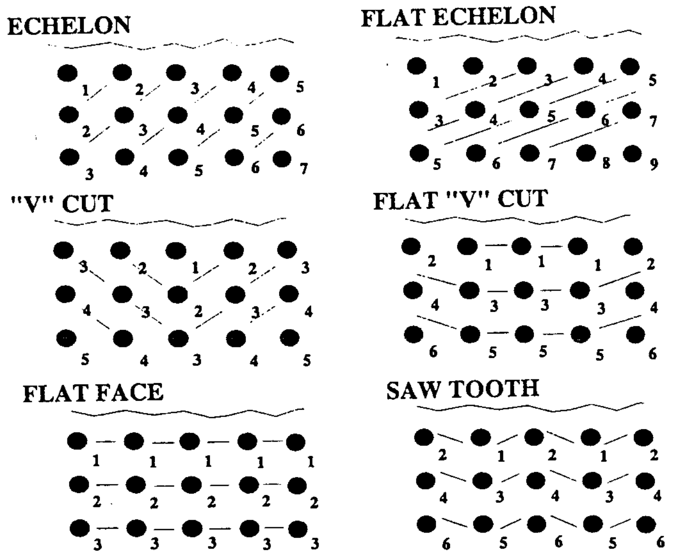
This equation can also be used to predict the weight of explosives for a given PPV.

$$\text{W(lbs/delay)} = \left[\frac{\left((\mathbf{dis\,tan\,ce})^{-1.6}\right)\mathbf{x}160}{\mathbf{PPV}}\right]^{2/-1.6}$$

CHAPTER 4
SHOT TIMING

As discussed in Chapter #2, the most important element to the success of a multi-charge blast is the proper use of the initiation system. Chapter #2 covered the types and hook-up configurations of initiation. This chapter will focus on shot timing or delay sequencing. The use of proper delay sequencing provides fragmentation control, displacement, direction of movement, reduction of vibration , airblast, and flyrock, highwall stability, and reduction of potential misfires.

The primary focus of shot timing design is "relief". Since the best blasting results occur when a free face is present, delay sequencing provides a means of creating free faces internal to the rock mass being blasted. To accomplish this, the hole nearest the point of most relief detonates first. This creates a new free face. The hole nearest the new free face detonates second, creating another new free face. This continues until all charges have detonated. The various sequencing patterns have been given names (Figure 4.1). Some blasting situations do not have a free face. When this occurs, the blaster must initially use the surface of the bench as the open face and lift the material with the initial holes. This usually requires a slightly higher powder factor in the vicinity of the opening holes. Once the opening holes have detonated the remaining holes are sequenced to relieve toward the area of the opening holes. This shot pattern is called a sink shot and is discussed at the end of Chapter #3.


ECHELON

FLAT ECHELON

"V" CUT

FLAT "V" CUT

FLAT FACE

SAW TOOTH

Figure 4.1

Millisecond delay detonators are the most common initiation systems used in surface blasting. The actual timing of each explosive charge depends on many things, some or all of which may be applicable in given blast. These items are listed below:

Geology: Different rock types and geological structures require different delay timing and sequencing. As an example, harder rock reacts faster to explosive energy than softer rock, which absorbs energy and does not displace as fast. Soft rock may require a slightly longer time delay in the detonation sequencing.

Drill Pattern: The size of the pattern (burden and spacing) and the pattern geometry will affect the delay timing and sequencing. Larger patterns will require longer time delay between detonations.

Displacement: The distance and direction of displacement is determined by the timing and sequencing of the delay initiation system.

Fragmentation: The timing of a blast is critical to the proper utilization of the explosive energy and the ultimate fragmentation of the rock mass. Based on pattern geometry, and geology, changes in timing may cause a marked difference in fragmentation.

Vibration: As mentioned in Chapter #5, the two major contributing factors to vibration are confinement and charge weight per delay. Proper shot timing and sequencing provide internal free facing and detonation frequency which are essential in vibration control. The use of delays in controlling charge weight per delay is discussed in detail later in this chapter.

Air Overpressure: Poor relief timing or timing across the front row of holes greater than 1100 feet per second may result in increase air overpressure (airblast).

Flyrock: Delay sequencing, which produces poor relief or unburdens undetonated blast holes provides the possibility of flyrock.

Highwall Stability: Proper delay sequencing will enhance highwall stability by providing proper relief and reducing back pressure on the wall behind the blast. This provides safer working conditions and better blast performance on subsequent blasts.

Misfires: The use of proper timing and sequencing will reduce the potential of misfired explosives. As a general rule, to prevent cut-off's and misfires, all detonators in the blast should be energized before the first hole detonates.

System and delays: The actual firing sequence and timing is usually the responsibility of the blaster and depends on the system and delays he has available. It is important that the blaster have some flexibility in the timing and sequencing design of a blast. This may require the stocking of additional delay units.

In calculating the actual firing times in a blast, a blaster should use his experience to determine the timing and sequencing that works best. Some general guidelines for surface blasting to an open face are:

1. Delays between holes in a row should be 1 millisecond to 5 milliseconds per foot of burden.
2. If front row holes spacing is reduced to handle additional toe burden, front row timing

between holes in that row should be reduce proportionally to the spacing reduction.

3. Delays between rows of holes should be from 2 to 4 times greater than the delay between holes in a row. Blasts with greater than three rows of holes may find it advantageous to slightly increase the delay between the back rows of holes.
4. Detonation rate across the open face should be less than half the speed of sound
5. The minimum time separation between delay periods is 8 milliseconds. Adjacent holes and decks in a hole should be separated by a minimum of 17 milliseconds.

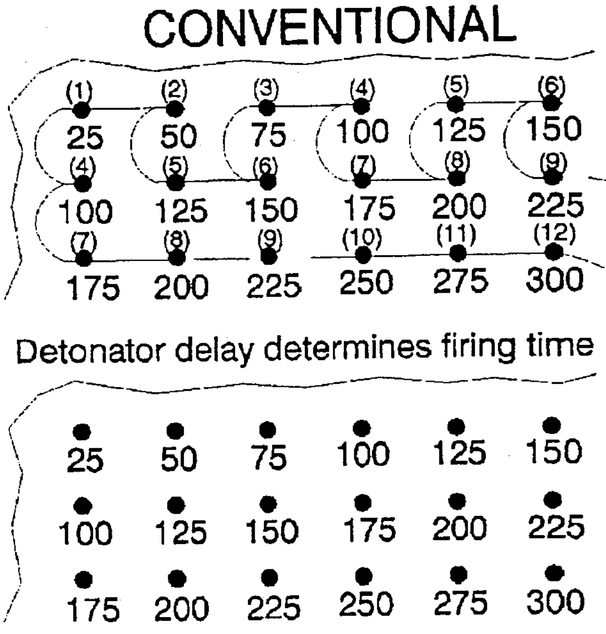


Figure 4.2

In performing delay timing calculations, there are three different delay systems to be considered:

Conventional Electric: In this system, the electrical energy is delivered to each detonator in the blast at the same time. The actual firing sequence is determined solely by the delay in the electric detonator and its placement in the delay pattern (Figure 4.2). For example, a 50 millisecond detonator will fire at 50 milliseconds after the fire button is pressed. To prevent potential cut-offs and misfires, instant detonators should not be used in conjunction with delay detonators.

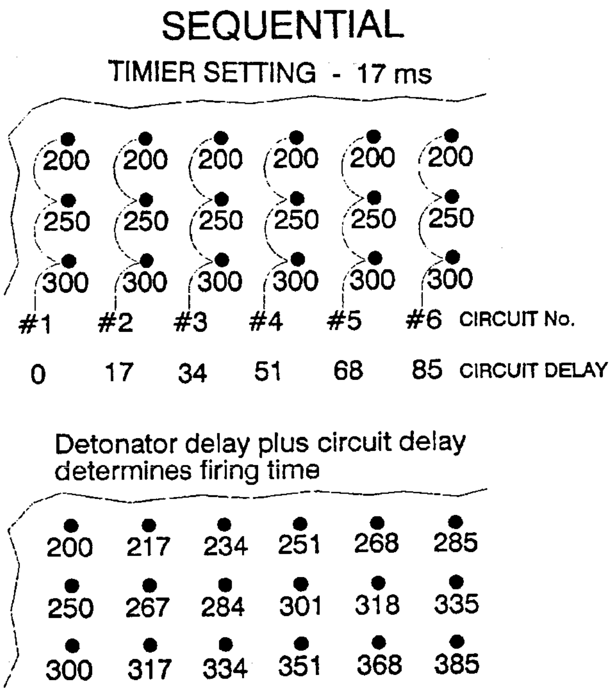


Figure 4.3

Sequential Electric: In this system, the electrical energy is delivered at preset timing intervals to each of the 10 blasting circuits. Circuit 1 energizes when the fire button is pressed. Circuit 2 waits for the preset time interval to pass and then it will energize. Circuit 3 waits the preset time interval after circuit 2 energizes and then it energizes. This sequencing continues until all circuits energize. The actual detonator firing time is dependent on the detonator delay, the circuit to which it is connected and the preset time interval (Figure 4.3). For example, if a 250 millisecond detonator is connected into circuit 3 and a 17 millisecond time interval is set on the sequential timer, the detonator would fire at 284 milliseconds after the fire button was depressed

(17 ms 1to2, + 17 ms 2to3 + 250 ms in detonator).

Non-electric: In this system, the non-electric energy source is delivered through a network of surface delays to the individual holes. As the energy source progresses across the surface of the bench, the timing to energize each hole becomes additive. The actual detonator firing time is dependent on the in-hole detonator delay and the additive delay time that the hole was energized (Figure 4.4). For example, if a 350 millisecond in-hole delay detonator is placed in the third hole of the second row and a surface delay pattern using 25 milliseconds between holes in a row and 17 millisecond between rows connected on a diagonal is utilized, the detonator would fire at 442 milliseconds after the blast was initiated (25 ms hole 1to2 + 25 ms hole 2to3 + 25 ms hole 3to4 + 17 ms row 1 hole 4 to row 2 hole 3 + 350 ms in-hole detonator).

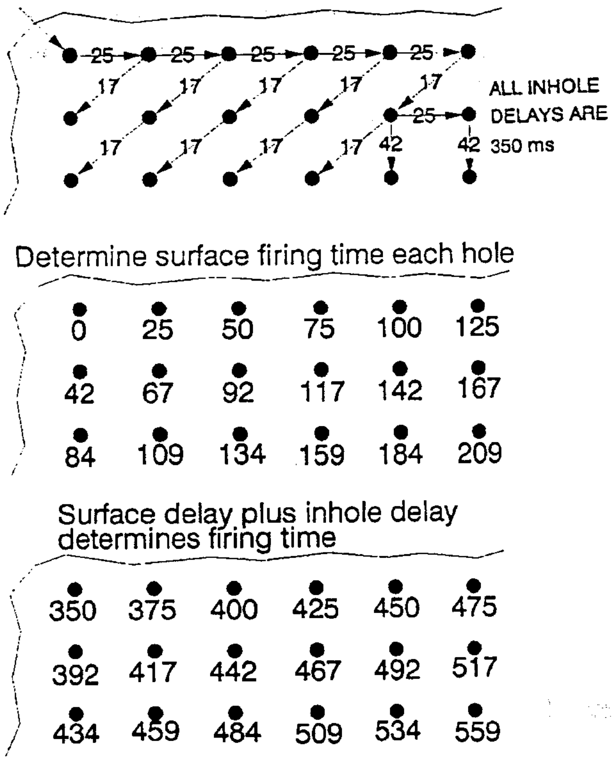


Figure 4.4

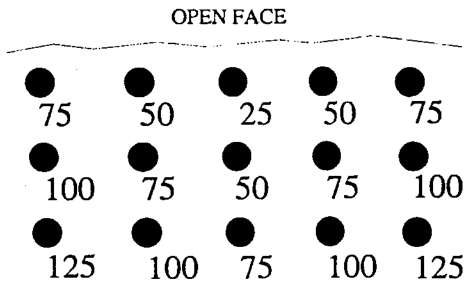
As mentioned above, shot timing is used to control vibrations levels. This is accomplished by limiting the pounds of explosive detonated in an eight (8) millisecond period (pounds per delay). The method for calculating pounds per delay is five step procedure:

1. Determine the charge weight of each explosive charge in the blast. This information can be pounds of explosives actually field loaded or can be calculated using methods discussed in Chapter 3. Be sure to include all the explosives. (Add the weight of the primers, the blasting agent, and other explosive.)
2. Determine the firing time for each explosive charge (hole or deck in hole) in the blast.
3. Compare the firing time of each explosive charge to the firing time of every other explosive charge in the blast. If two or more firing times are within a time period less than eight (8) milliseconds, they must be considered to have the same delay.
4. Add the charge weights of the explosive charges that are considered to be on the same delay.
5. Determine the maximum pounds detonating within any one 8 millisecond delay period. If all charge weights are equal, calculation of pounds per delay can be simplified by multiplying the charge weight of one charge by the maximum number of charges within the 8 millisecond period.

Following are sample problems demonstrating the calculation of pounds per delay.

Example Problem - Conventional Electric:

The timing for an electric blast is shown below. Each hole in the front row contains 3 fifty pound bags of ANFO and 2 one pound cast primers. Each hole in rows two and three contain 4 fifty pound bags of ANFO and 2 one pound cast boosters. Determine the maximum pounds per delay.



Step 1

The front row holes each contain 152 pounds of explosive (50x3+2). Each hole in the second and third rows contains 202 pounds of explosive(50x4+2).

Step 2

The firing time is given by the millisecond delay for the detonator in each hole.

Step 3

Comparing the firing times there is one 25 ms hole, three 50 ms holes firing in one period, five 75 ms holes firing in one period, four 100 ms holes firing in one period, and two 125 ms holes firing in one period.

Step 4

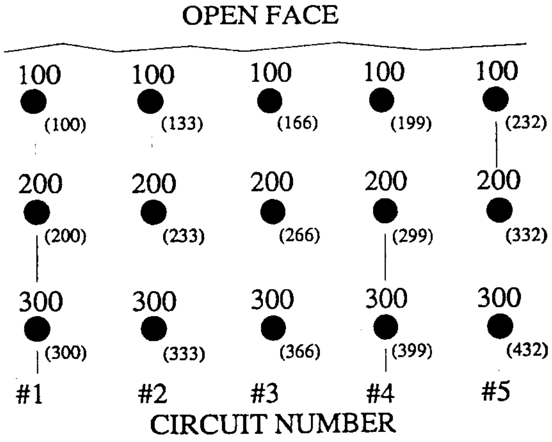
Adding the charge weights, the explosives firing in any 8 ms period are: 25 ms = 152 pounds, 50 ms = 506 pounds, 75 ms = 910 pounds, 100 ms = 808 pounds, and 125 ms = 404 pounds.

Step 5

Comparing the different charge weights detonating in any 8 ms period from Step 4, the maximum pounds detonating per delay is 910 pounds (at 75 ms).

Example Problem - Sequential Electric:

The timing of a sequential timer blast is shown below. There are 5 series circuits used in the blast and the timer setting between each circuit is 33 milliseconds. A bulk truck is used to load the shot with explosive having a loading density of 13.2 pounds per foot of borehole. Each 6¾" hole is loaded the same with 1 one pound cast booster and 24 feet of ANFO. Determine the maximum pounds per delay.



Step 1

Each blast hole contains 317.8 pounds of explosive (13.2 x 24 + 1)

Step 2

The actual firing time of each hole is calculated by adding the detonator delay to the time the circuit is energized. Circuit 1 is energized at zero millisecond, circuit 2 at 33 ms, circuit 3 at 66 ms, circuit 4 at 99 ms and circuit 5 at 132 ms. The actual firing times of the holes is represented by the number in parenthesis.

Step 3

Comparing the firing times each hole in the shot fires in its own 8 millisecond delay period except two holes which fire at 199 ms and 200 ms and two others which fire at 299 ms and 300 ms. because they are less than 8 milliseconds between detonations, the charges in each of these two sets of holes are considered to fire at the same time.

Step 4

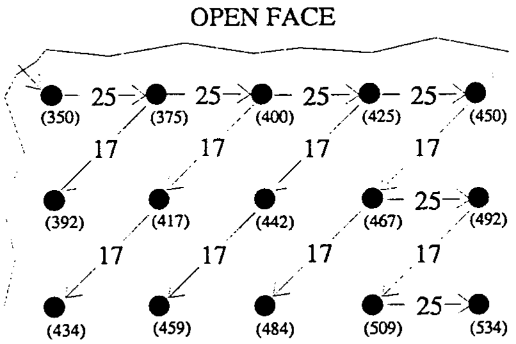
Each hole firing individually fires at 317.8 pounds per delay. The two sets having holes that fire within 8 ms, each fire at 635.6 pounds per delay (317.8 x 2)

Step 5

The maximum pounds per delay is 635.6 pounds.

Example Problem - Non-Electric:

In the non-electric blast is shown below, each hole is loaded with 150 pounds of 50-50 emulsion blend, 200 pounds of ANFO and 2 one pound cast boosters. Each hole contains the same 350 ms delay in-hole detonator. Determine the maximum pounds of explosives per delay.



Step 1

Each blast hole has the same amount of explosive, 352 pounds (150 + 200 +2).

Step 2

The actual firing time of each hole is determined by adding the in-hole delay detonator to the sum of the surface delays leading to that detonator. The first hole detonates at 350 ms (the in-hole detonator timing). The second hole detonates ant 375 ms (25 + 350). The third hole in row fires at 400 ms (25 + 25 + 350). The first hole in the second row fires at 392 ms (25 + 17 + 350). The second hole in the second row fires at 417 ms (25 + 17 + 25 + 350). The remainder of the holes are determined. The actual firing times are represented by the numbers in parenthesis.

Step 3

Comparing the firing times of each hole, it is determined that each hole fires in its own 8 millisecond period, thus only one hole per delay

Step 4

Since each hole, containing 352 pounds detonates independently, the pounds per delay for each hole is 352 pounds.

Step 5

The maximum pounds per delay is 352 pounds.

CHAPTER 5

ENVIRONMENTAL EFFECTS

The Federal Government and the State of West Virginia have established regulatory requirements addressing the effects of blasting on properties surrounding mining operations. These regulations cover vibration, airblast, flyrock, and dust. Failure to comply with these regulations may result in fines, litigation, loss of blaster's certification, or the closing of the operation. Control of unwanted environmental blasting effects is extremely important. It should be noted that compliance with the regulations does not guarantee that neighbor complaints will not occur. Even when regulatory limits are not exceeded, low level vibration or airblast may still result in complaints, litigation, and potentially tighter controls by regulatory agencies. It is in the blaster's and his company's best interest to address and minimize the environmental effects of blasting. To minimize environmental effects, the blaster and his crew must pay attention to the details: geology, shot design, shot preparation and drilling, and loading procedures.

PRE-BLAST SURVEY

When blasting in the vicinity of homes, hospitals, schools, churches and other man-made structures, a pre-blast survey documenting the conditions of the structures prior to the first blast is very beneficial. This survey serves a two-fold purpose. First, it increases communications between the community and the mine operation, developing a feeling of concern and trust between both parties. Many companies conducting pre-blasting surveys have found them a good investment, in that they reduce blasting complaints. The second purpose is to provide a baseline record of the condition of the structure against which the effects of blasting can be assessed. When combined with a postblast survey it helps assure equitable resolution of any blast damage claims.

Although blasters are not usually responsible for conducting pre-blast surveys, they may be held accountable for regulation violations such as detonating a blast before conducting required pre-blast surveys. This may result in the loss of his blaster's certification. The blaster must also be aware of any nearby structures which could be damaged by flyrock, air blast, or vibration.

Each owner of a man-made structure within 1/2 mile of the permit area must be notified in writing, at least 30 days prior to blasting, how to request a preblast survey. If the property owner requests a pre-blast survey, it should be completed within 30 days. Copies of the survey report shall be provided to the person requesting the survey and to WVDEP.

In most cases, a company's permit application for blasting withing 1,000 feet of structures requires plans for conducting pre-blast surveys for each man-made structure within 1,000 feet of the blast area. If a company fails to conduct these surveys and does not obtain permission from the WVDEP to conduct this blasting, the blaster detonating the shot within 1,000 feet of a structure is in violation of the law and could lose their certification.

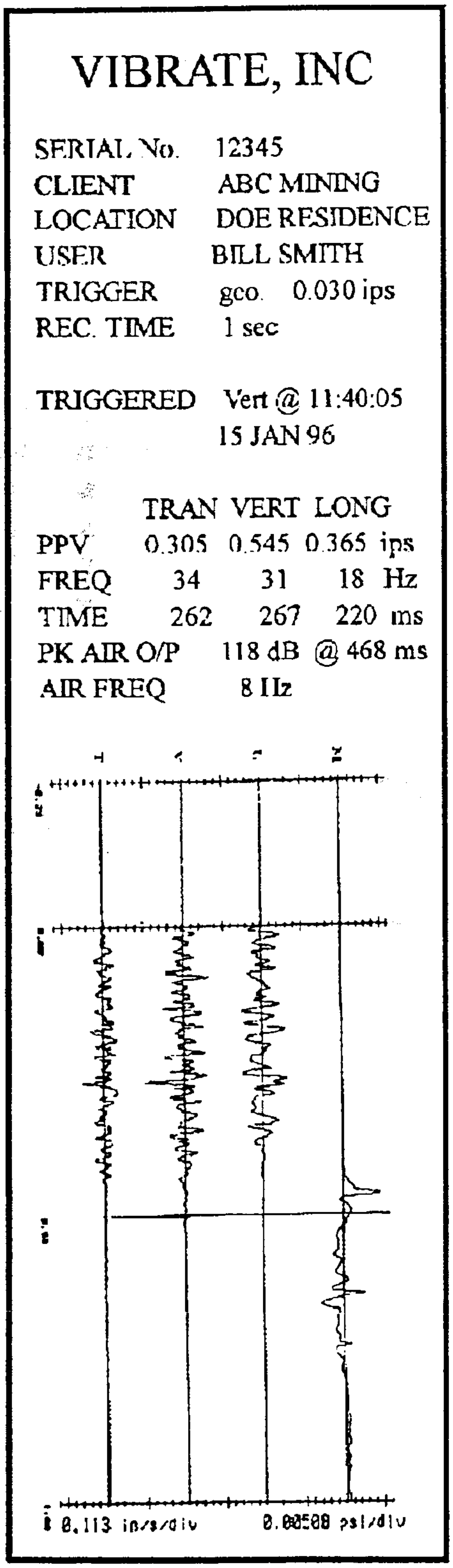
The requirements for public notice for blasting operations and the requirements for blast records are found in Section 38-2-6.3 of the state regulations (See Appendix B).

VIBRATION:

All blasts create ground vibrations. Ground vibrations can cause property damage and may be bothersome to some people. It is not likely to cause personal injury. The areas of concern are not only homes and other surface structures, but also dams, wells (oil, gas, water), pipelines, roads, bridges, pit slopes, spoil piles, underground workings, etc. Structures owned by the permittee and not leased to another person and structures owned by the permittee and leased to another person who has signed a waiver shall not be subject to the maximum vibration and airblast limitations.

When explosives are detonated, the rapid release of energy generates compression waves which are sent outward in all directions. This compression wave energy is required to fragment rock. Energy, not consumed in fragmentation, extends outward through rock, earth, water, etc., as vibration. This vibration is characterized by the displacement (inches), particle velocity (inches per second), and the frequency (cycles per second or Hertz). Studies conducted by the US Bureau of Mines on vibration, determined that particle velocity was the easiest and most representative of these to monitor. The studies also determined damage criteria used in establishing the limits currently enforced by the Federal and State Governments. Ground vibrations are measured with a seismograph (Figure 5.1). In order to do his job effectively, the blaster should be familiar with the proper use of a seismograph, as well as the data it provides. Although different seismographs have different setup and operation procedures, several factors are common to all units. The geophone must be coupled in intimate contact with a stable material , either earth or rock. It should not be placed on grass, decomposed vegetation, concrete or asphalt slabs, near tree roots, inside of structures, or in swampy areas. The arrow on the geophone should point toward the blast. The microphone should be positioned to allow free access from all sides, preferably on a stand. Understanding the data generated by the seismograph is equally important (Figure 5.2). The most important data includes the peak particle velocity for each of the three mutually perpendicular vibration planes, the peak air overpressure, and the vibration frequency. This information should

Figure 5.1



VIBRATE, INC

SERIAL No. 12345
CLIENT ABC MINING
LOCATION DOE RESIDENCE
USER BILL SMITH
TRIGGER geo. 0.030 ips
REC. TIME 1 sec

TRIGGERED Vert @ 11:40:05
15 JAN 96

	TRAN	VERT	LONG	
PPV	0.305	0.545	0.365	ips
FREQ	34	31	18	Hz
TIME	262	267	220	ms

PK AIR O/P 118 dB @ 468 ms
AIR FREQ 8 Hz

Figure 5.2

be transferred to the seismograph data section of the blasting log. Other data provided by most modern seismographs includes peak displacement, quarter wave displacement, particle acceleration, peak vector sum, and sound pressure level. Although not normally applied, this data may be significant under certain conditions.

Excessive ground vibrations are caused by factors such as poor blast design or lack of attention to geological conditions. The two primary blast design criteria for controlling excessive vibration are avoiding overconfinement (Figure 5.3) caused by excessive burden, improper timing, or low powder factor and limiting pounds of explosive detonated in an 8 millisecond period. In overconfinement, the explosive energy cannot fragment and displace the rock properly and much of the confined energy is converted to ground

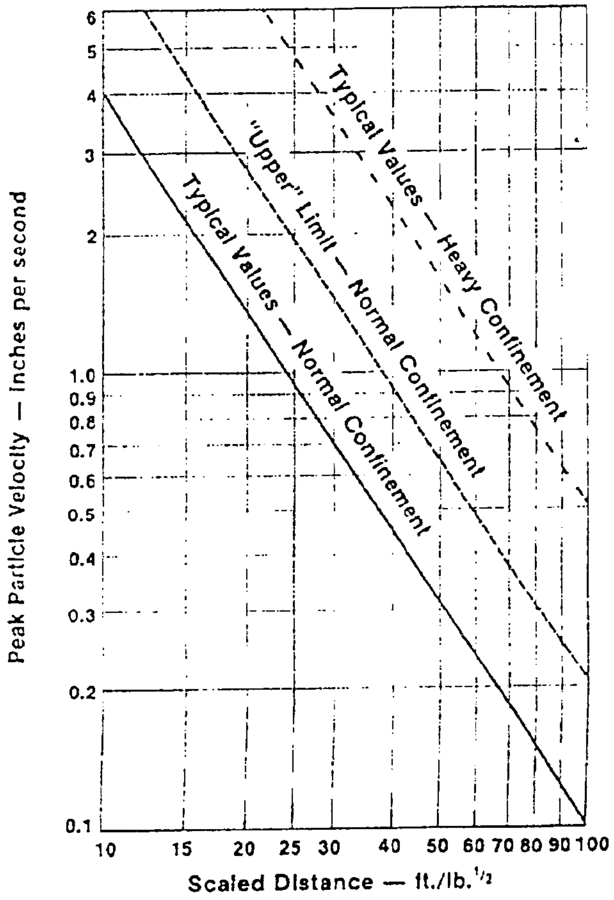


Figure 5.3

vibration. The limiting of pounds per delay controls the amount of energy released at any given point in time.

The most elementary equation used in vibration blast design is the Scaled Distance Formula (Equation 5.1). This formula, which utilizes the distance from the blast to the protected structure and the charge weight per 8 millisecond delay period, is used to predict or control ground vibration.

Equation 5.1: $SD = D / W^{1/2}$ or $W = (D / SD)^2$

where SD = scaled distance

D = distance from the blast to the structure (feet)

W = maximum charge weight in pounds per 8 milliseconds delay

The Office of Surface Mining and the West Virginia Division of Environmental Protection have established charge weight limits based on the use of the Scale Distance Formula. These limits apply for any blast where a seismograph is not being used.

LEGAL LIMITS FOR SCALED DISTANCE FORMULA

0 - 300 ft.	$W = (D/50)^2$
301 - 5,000 ft.	$W = (D/55)^2$
5,001 ft. and over	$W = (D/65)^2$

Where: W = Maximum allowable weight of explosives per 8 ms delay period

D = Distance to the nearest protective structure

Example Problem:

The nearest structure is 1,200 feet from the blast site. What is the charge weight per 8 millisecond delay period (W) allowed for this blast.

Since the structure is 1200 feet, a scale distance of 55 must be used.

$W = (D / SD)^2 = (1200/55)^2 = (21.82)^2 = 476$ pounds / delay

If a seismograph is utilized at the nearest protected structure, charge weights greater than those calculated with the scale distance formula may be used as long as the peak particle velocity recorded on the seismograph does not exceed the OSM / WVDEP legal limits.

LEGAL LIMITS FOR PEAK PARTICLE VELOCITY

0 - 300 ft.	1.25 inch per second
301 - 5,000 ft.	1.0 inch per second
5,001 ft. and over	0.75 inch per second

The Scaled Distance Formula is very conservative and has a built in safety factor. Typically, a SD factor of about 25 or lower is needed to create vibrations around 1.0 in./sec. The Scaled Distance Formula approach works well when the blast site is an adequate distance from structures. At short distances, the Formula becomes restrictive in terms of allowable charge weights per delay, in which case it may be more practical to monitor the blasting with a seismograph.

Because of neighbor complaints, it is sometime advantageous to estimate the peak particle velocity for a given blast (Equation 5.2). This equation assumes that the blast is detonated under normal confinement.

Equation 5.2 $$PPV = A \; x \; (SD)^{B}$$

where PPV = peak particle velocity (inches per second)
SD = scale distance (distance (ft) / charge weight (lbs)$^{1/2}$)
A = confinement factor (nominally 160)
B = slope factor (nominally - 1.6)

Vibration frequency, expressed as cycles per second or Hertz, is very important in vibration control. Soft rock and loose earth, such as the sandstones, shales, and soils found in coal mining operations, tend to carry low frequencies. Unfortunately, low frequencies travel greater distances than higher frequencies. Furthermore, the natural frequency of structures is in the frequency range of 5 and 20 Hertz. This is the reason for the reduction in limits with distance in the above tables. As the distance gets larger, the higher frequencies are lost and only the low, potentially damaging frequencies remain. This is also shown on the USBM / OSMRE plot (Figure 5.4), which plots the damage criteria curve for plaster with respect to peak particle velocity and frequency.

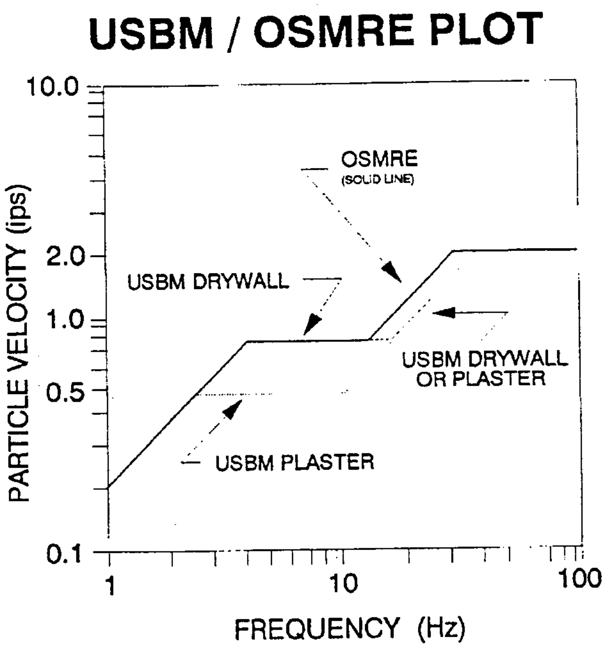


Figure 5.4

The response of the human body to vibrations is also greater at lower frequencies. This explains why people file complaints even when the blasting is being conducted at safe (no damage) levels. The response of the human body to vibratory motion at 20 Hz is perceptible at a particle velocity of about 0.04 inches / second, unpleasant at 0.2 inches / second and intolerable at 0.8 inches / second (Figure 5.5). All of these values are below safe limits for residential structures.

Ground vibrations can be reduced by properly designing the blast, using a spacing-to- burden ratio of 1.0 or greater, using proper delay patterns and a proper powder factor. Blasthole locations should be carefully laid out and marked and drilling should be controlled and done properly. Poor drilling practices can lead to poor blasting results. The following techniques can be used to possibly reduce ground vibrations.

1. Reduce the weight of explosive per delay (W). This can be done by reducing the number of blastholes on each delay, by using smaller hole diameters, smaller bench heights and/or by decking the charges.
2. Avoid overly confined charges caused by burdens being too large or by excessive subdrilling.
3. Increase the length of delay between charges.
4. Initiate the holes in an order that will propagate in a direction away from the structure of concern.
5. Time the blasting during periods of high local activity and avoid quiet times.
6. Increase the scaled distance factor from 60 to 65 or 70.
7. Use a sequential timer or non-electric initiation to increase the number of delays.

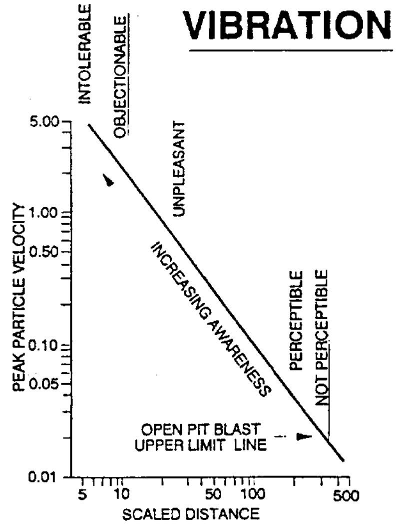


Figure 5.5

Complaints from ground vibrations and air blast are often due to the annoyance factor, fear of damage and the startling effect of the blast. In most cases actual damage does not occur. The human body is very sensitive to low vibration and air blast levels but is not a reliable damage indicator. Other factors resulting in complaints are the attitude toward the mining operation, how often and when the blasts are fired, and the duration of the vibrations (they should be limited to less than one second when possible). It is essential to investigate every blast complaint as soon as possible after it is received. Be friendly, open and listen to the complaint. Do not be confrontational. By demonstrating your concern, you will reduce the possibility of the situation escalating into regulator control and litigation. Keep files on all complaints and actions taken.

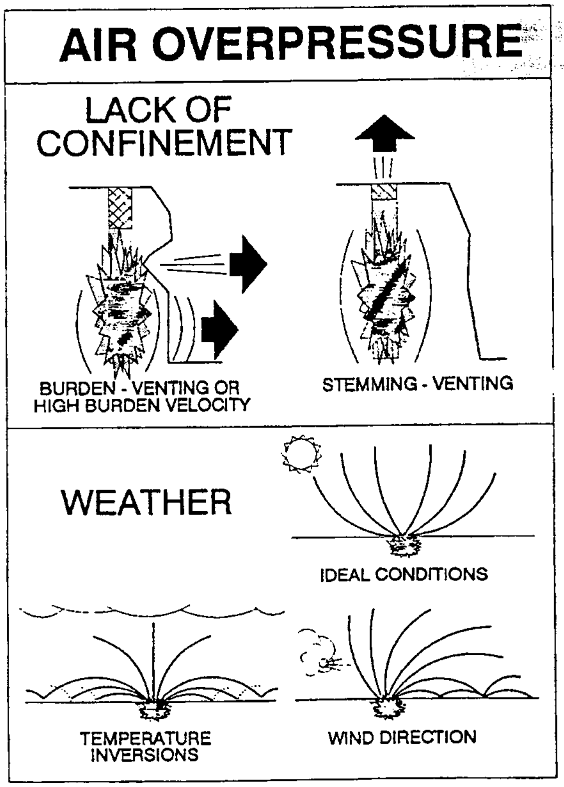


Figure 5.6

AIR OVERPRESSURE

Air overpressure or airblast is a shock wave traveling through the air as a result of explosives detonation. It may be caused by rapid movement of burden or the release of expanding gas into the atmosphere (Figure 5.6). Audible airblast is called noise. Airblast at frequencies below 20 Hz, inaudible to the human ear, is called concussion. Airblast annoyance and damage are related to the blast design, terrain, weather conditions and human response. It is measured with special gauges, pressure transducers or wide-response microphones. The seismograph shown in Figure 5.1 is equipped to monitor and record both ground vibrations (through the geophone) and airblast (through the microphone pick up). As with ground vibrations, both amplitude (in decibels) and frequency (in hertz) are measured.

Airblast damage has been studied by the USBM and air blast limits set by OSM and WVDEP are listed below:

LEGAL LIMITS FOR AIRBLAST

Airblast shall not exceed the maximum limits listed below at the location of any dwelling, public building, school, church, or community or institutional building outside the permitted area.

Lower Frequency Limit of Measuring System in Hz (± 3 dB)	Maximum Level dB
0.1 Hz or lower - flat response[1]	134 peak
2 Hz or lower - flat response	133 peak
6 Hz or lower - flat response	129 peak
C - weighted - slow response	105 peak

1 - Only when approved by Director

Most commercial seismographs used for monitoring air overpressure today are manufactured to the industrial standard of 2 Hertz.. Airblast levels should be kept as low as possible. Some representative values are given in Figure 5.7 along with a conversion from decibels (db) to pounds per square inch (psi).

dB	psi	
180	3.0	← Structural Damage
170	0.95	← Most Windows Break
160	0.30	
150	0.095	← Some Windows Break
140	0.030	
130	0.0095	← USBM Maximum ← USBM Safe Level
120	0.0030	← Complaints Likely
110	0.00095	
100	0.00030	
90	0.000095	← OSHA 8 Hour Maximum
80	0.000030	

Figure 5.7

It is very difficult to predict or control the motion of air concussion waves (Figure 5.6). Wind direction can force air concussion in the direction that it is blowing. A temperature inversion (a layer of warm air above a layer of cold air) can cause the air blast to bounce back toward the ground. The combined effect of wind and a temperature inversion can cause severe airblast problems. Generally, if a blast is designed to control ground vibration; and, if sufficient stemming is used, air concussion and noise will not be a problem. Airblast can be reduced by the following methods:

1. Do not use unconfined explosives. Bury any surface detonating cord and use those with lighter core loads.

2. Use adequate burden and stemming of the blastholes. Good blast round design is essential.
3. Geologic conditions that cause blowouts should be compensated for. These include mud seams, voids, open bedding and cavities or other openings.
4. Holes must be drilled accurately. This is especially true of inclined holes.
5. Avoid high free faces in the direction of structures.
6. Avoid collar priming (seldom used anyway).
7. Avoid detonating blast during early morning, late afternoon, at night, during temperature inversions or other undesirable atmospheric conditions.
8. Use delays between rows longer than those between holes in a row to promote forward rather than upward burden movement.
9. Avoid long delays that may cause a hole to become unburdened before it detonates.

FLYROCK

Flyrock is rock that is propelled through the air or along the ground from a blast. It is extremely dangerous and is a potential cause of death, injury and property damage. Excessive flyrock may be caused-by poor blast design, zones of weakness in the rock, or powder factors too high for the rock being blasted. It is a leading cause of on site fatalities and equipment damage from blasting. Flyrock has killed people over a mile from the blast site.

Flyrock has two sources, the open face of the bench and the surface of the bench (Figure 5.8). To reduce the potential for flyrock, the blaster should insure proper rock burden for the explosive charge used, develop good blast round design and use proper stemming (both amount and type). A one-fourth inch size material makes better stemming than fines especially where there is water in the blasthole. Additional stemming should be used in areas where the bench surface contains material that is already fractured. With a hard caprock, sometimes it is better to increase the stemming height and use a small deck charge to break the caprock. Avoid collar initiation whenever flyrock is a problem. The same conditions that cause airblast can also cause flyrock.

Even with good blast design and careful planning and loading, flyrock may occur. A blast area should be established which encompasses an area which would contain all flyrock. Any persons within this blast area (including the blaster) must have safe cover and must be adequately warned prior to blasting. All persons not required by the blasting activities should be

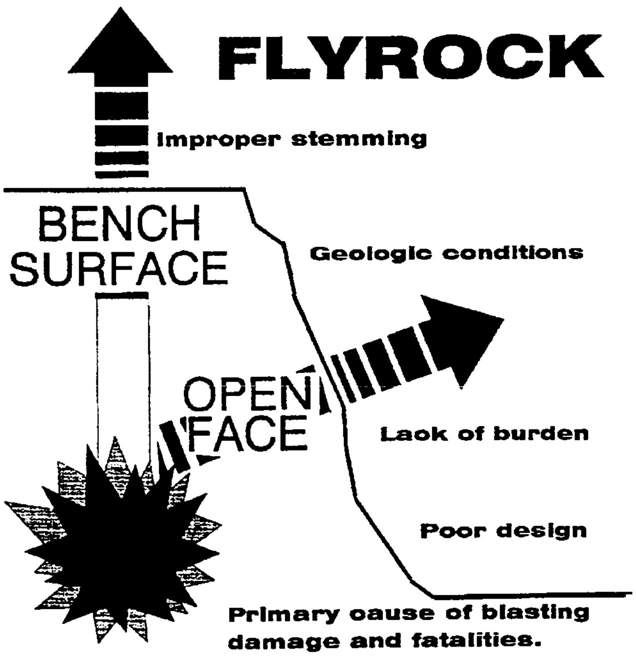


Figure 5.8

removed from the blasting area and the area should be guarded against unauthorized entry. Abnormally long flyrock distances should be measured and recorded for future reference. This should be a factor in determining the guarded perimeter of the blast area.

LEGAL LIMITS FOR FLYROCK

OSM and WVDEP regulations state that flyrock, including blasted material, shall not be cast from the blast site more than one-half the distance to the nearest structure or other occupied structure, beyond the blast area control perimeter and in no case beyond the permit boundary.

There might also be local flyrock regulations. For small, close in construction shots, special protective mats should be considered.

DUST AND FUMES

Surface blasting may create dust clouds during blasting operations. This may foster neighbor complaints. Wind direction and velocity should be considered when dust from blasting is a problem. In most operations the dust generated by loading, hauling, crushing and processing operations far outweighs the dust created by blasting. These sources are more easily controlled by wetting. Often correction of these sources will eliminate the overall dust complaint.

Fumes are normally not a problem with neighbors. A poorly mixed explosive material or an inefficient explosive reaction can produce carbon monoxide (colorless) or oxides of nitrogen (orange-brown fumes). The quantities produced are seldom significant and are normally not considered a source of air pollution. These gases are considered toxic at levels of 50 ppm and 5 ppm respectively. They normally are diluted below these levels by the natural air movement, but locally may be harmful to the blast crew if they return to the blast area too soon.

Oxides of nitrogen are caused by poor blasting agent mixtures, degradation of explosives during storage, desensitization or separation when coming in contact with water and inefficient initiation procedures. If large amounts of orange-brown fumes are observed after the blast the source of the problem should be determined and corrected.

BLASTER'S NOTES

CHAPTER 6
BLASTING SAFETY & PROCEDURES

REGULATIONS

Federal, State, and Local government agencies establish laws which govern the way we live and work. The shipping, storage, handling and use of explosives is no exception. These laws, published in the form of regulations, are not intended to burden the blaster, but to provide guidelines for safety and protection of property and the environment. The blaster should be familiar with all blasting regulations which are applicable to his operation (Appendix A, B, C, D, and E and the Code of Federal Regulations 30, Mineral Resources)

To protect the safety of personnel and property, each blaster responsible for surface blasting operations shall be certified by The West Virginia Division of Environmental Protection. To become certified the blaster must have at least one (1) year of active blasting experience within the past five (5) years and demonstrate his knowledge in the transportation, storage, handling and use of explosives by successfully completing the training and examination provided by WVDEP. Each certified blaster shall have proof of certification either on his person or on file at the permit area during blasting operations. The certified blaster shall be familiar with the blast plan and blast related perfomance standards for the operation at which he is working. A blaster's certification may not be transferred or assigned to another individual, nor may the certified blaster delegate his blasting responsibility to another individual unless he is a certified blaster. Blaster certification is issued by WVDEP for a period of three (3) years and must be renewed at the end of that period.

All operations at which blasts are to be detonated utilizing more than five (5) pounds of explosives must submit a blast plan to WVDEP. The blast plan shall explain how the operation will comply with the requirements of the regulations. Any blast to be detonated within one thousand (1000) feet of a dwelling, public building, school, church, or community or institutional building, or within five hundred (500) feet of an active or abandoned underground mine, shall submit a blast preplan for the specific area prior to blasting. The plan must be signed by a certified blaster.

At least ten (10) days, prior to any blasting operation, the operator shall publish a blasting schedule. The blasting schedule shall contain at a minimum:

(a) Name, address, and telephone number of the operator
(b) Identification ot the specific areas in which blasting will occur
(c) Dates and times when explosives are to be detonated
(d) Methods to be used to control access to the blasting area, and
(e) Types of audible warning and all clear signals to be used before and after each blast

The operator shall republish the schedule every twelve (12) months. If the schedule is significantly changed, the revisions must be published at least ten (10) days but not more than thirty (30) days, prior to the revisions being implemented. Blasts may be detonated only during daylight hours (sunrise to sunset) and only during times periods approved on the blasting schedule.

The operation should define the blast area to allow for both safety of personnel and area security. The blast area shall be posted with warning signs at all entrances and along any edge when it comes within one hundred (100) feet of a public right-of way. A sign defining the blast warning signals shall be posted at the entrance to the permit area.

Besides blaster's certification, the blast plan and the blast schedule, the regulations cover the other aspects of blasting such as storage, transportation, blast procedures, vibration, airblast, flyrock and misfires. These regulations are covered in detail in the various chapters of this study guide. Failure to comply with regulations can result in the withdrawal of the blaster's certification, fines, the closure of the mine, etc.

PRESHOT PREPARATION

Planning and preparation are essential to the success of any blast and should be under taken days if not weeks before the date the actual blast is to take place. First the area to be blasted must be defined and checked for safety concerns such as ground stability and potential misfires from previous blasts. Second the bench area cleared and leveled. Third the blast round must be designed. This would include determination of the bench height, hole depth, drill pattern, number of blastholes, distance to protected structures, types and quantities of explosives, delay initiation requirements, loading and timing configurations, and projected time for loading and detonation. The latter is a function of expected drill time, excavation time to clear pit area in front of blast, production requirements, and weather.

The blaster should layout the designed blast drill pattern to insure accuracy. This can be done on paper or better yet by physically locating the holes on the blast bench with stakes or painted rocks. The blaster should check during the drilling operation to determine potential change requirements, such as water levels, or geologic faults, which may affect the blast design. This will allow time to obtain any additional explosives, initiation, or accessories required to implement the design changes. Drilled accuracy is a must. Poorly drilled shot patterns can cause cutoffs, flyrock, and bad breakage. Drillers should have and use a weighted tape to check patterns and hole depths. The drillers should keep a detailed drill log of the conditions they encounter during the drilling operation. Items, such as mud seams, water levels, faults, voids, old workings, and broken material depth at the hole collar, should be made available to the blaster to insure safety and proper loading.

The blaster should check his explosives inventory to insure he has the proper types and quantities of explosives and initiation components for the blast as designed. He should also check the loading equipment, initiation devises, tools and monitoring equipment, to insure they are present and in good repair. Additional products and materials should be ordered in plenty of time to allow delivery prior to blast day.

Finally the blaster should monitor the weather reports and the progress of the blast preparation so as to make timely changes to the blast schedule as needed. If these preparations are made, the day of the blast will go smoothly.

BLASTING TOOLS AND ACCESSORIES

Figure 6.1

To safely perform the duties of blasting, the blaster must have the proper tools and accessories. The types of tools and accessories required depend on the type of operation and general blast conditions encountered, the type of explosives used, and the initiation system employed. Common tools include a pocket knife, powder punch, wire strippers, fuse-cap crimper, weighted measuring tape, lowering hook, retrieval device, and loading poles (Figure 6.1). Tools that may come in contact with explosives must me made of a non-sparking material and kept in good repair. Other tools such as an abney level, lightning detector, warning signs, and initiation testing and firing devices (discussed in Chapter #2) are essential to insure personnel safety. Tools must be used properly and in a manner for which they were designed. They should never be used in a manner which would compromise the blaster and other personnel. As examples, never attempt to tamp a primer through an obstruction in a blast hole, never try to pry a detonator stuck in primer, never force a detonator into a primer, never use an electrician's multimeter to test an electric initiation circuit, always use an approved initiation device, and always vacate the blast site during an electrical storm. Each of these has led to fatalities.

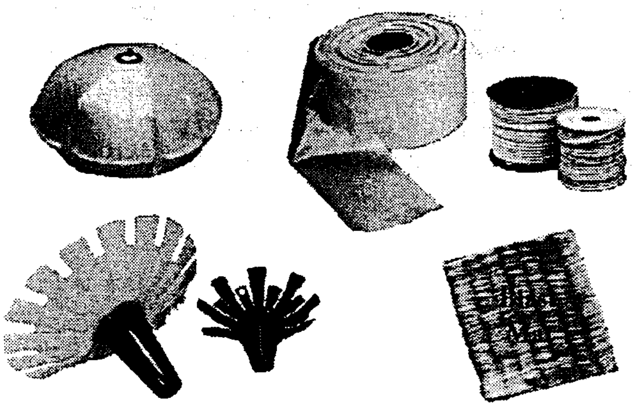


Figure 6.2

Accessories such as borehole liners and plugs (Figure 6.2) should be properly sized and available as needed. When blasting in close proximity to structures, a blasting mat should be considered.

PRIMING AND LOADING PROCEDURES

On the day of the blast, the blaster should first check weather conditions. Electrical storms, even without visible lightning, could cause premature initiation of a blast. Work on a blast site should stop whenever electrical storms are approaching or occurring in the area. Next the blaster should check the open face for potential changes in burden on the front row holes. He should check for ground stability, both on the crest of the blast bench and on highwalls above and in near proximity to the blast bench. He should also check depth and condition of each blasthole. A weighted fiberglass or cloth tape is the best tool for measuring and checking boreholes. On a sunny day, a mirror may also be used to check the hole conditions. If a borehole is obstructed it should be cleared prior to the introduction of any explosives. This may be done with a tamping pole or other suitable device. If redrilling is required, it may only be done if no explosives are loaded in holes closer than 50 feet in radius from the obstructed blasthole. Also changes in water conditions should be checked. If holes are to be dewatered, it is important to know whether the water conditions are static or dynamic. Dynamic conditions will require the use of wethole products. If wethole products are used, changes in initial water levels will require additional wethole product.

The amounts and types of explosives delivered to the blast site are determined by the blast round design (number, diameter and depth of holes) and whether water is present in the holes. Blasters should make pre-blast logs or loading charts to determine the quantity and distribution of explosive materials needed on the blast bench.

At least 10 minutes before loading starts, the blast area must be barricaded, clearly marked with signs, flags, cones or other markers. All unnecessary equipment must be removed from this area. Only the powder crew and authorized personnel under the direction of the blaster should be present. If an electric initiation is being used, any electrical power that might create a hazard should be disconnected, extraneous electricity checks should be conducted, and two-way radios in the vicinity turned off.

Safety and safe working habits are every blaster's responsibility. Every person involved with explosives must constantly make a conscious effort to work in a safe manner, always use proper procedures and never take chances. If questions arise and you are unsure, ask someone who knows, find out the right information, don't guess and hope you are right. The abuse or misuse of explosives can cause injury or death. It is important that proper techniques are learned, by study and experience, and developed into habits. The regulations in Appendices A, B, C, D and E do not cover every possible situation. It is important that the blaster and his crew be familiar with all company safety regulations which govern the operation. In summary, explosive safety depends on a thorough knowledge of the explosives involved, the applicable regulations, experience and most important, common sense.

Before loading is to commence, all persons on the loading crew should be familiar with the specifics of the blast design and the loading sequence. When possible the loading sequence for blastholes should progress from the closed end of the blast bench toward the open end and from the front row holes toward the back row. This sequence will minimize the need to cross loaded holes and will allow partial detonation of the blast, if all holes can not be loaded.

PRIMING

The initial phase of loading a blasthole is the assembly and loading of the primer. A primer consists of a cap sensitive high explosive (booster) and an initiation device (detonator or detonating cord). As a general rule of thumb, the booster should be of sufficient mass and diameter to insure proper detonation of the main explosive charge and should have a detonation pressure equal to or greater than that of the main explosive charge. Detonation pressure (P_d) can be approximated by knowing the density of the explosive (ρ) and the velocity of detonation (V). Density and velocity values are available from the explosive manufacturer.

Equation 6.1: $P_d\ (\text{Kb}) = 2.325 \times \rho(\text{g/cc}) \times V^2\ (\text{ft/sec}) \times 10^{-7}$

Note: 1 Kilobar (Kb) = 1,000 bars
1 bar = 14.5 psi = 1 atmosphere (atm)

Example Problem:
The loading density of ANFO is 0.85 g/cc and the detonation velocity is 13,000 ft/sec. Determine the detonation pressure.

$P_d = 2.325 \times 0.85 \times (13{,}000)^2 \times 10^{-7} = 33.4\ \text{Kb} = 33{,}400\ \text{atm}$

Boosters and detonators are delivered to the blast bench separately and should not be assembled to form primers until they are ready to be loaded into the blastholes. The person assembling the primers must be knowledgeable and experienced in their preparation. An improperly prepared or placed primer might malfunction or create series problems when the blast is fired. Assembled primers should never be left on the blast bench surface nor returned to storage.

Figure 6.3

Although any cap sensitive high explosive can be used as a booster (dynamite, cartridged water gels, cartridged emulsions, and mini-boosters), probably the most popular is the cast booster (Figure 6.3). Cast boosters are normally made from one or more ideal explosives such as TNT, PETN, Comp B or Pentolite. The cast booster offers several advantages. Being an ideal explosive, its performance is not affected by diameter, temperature, etc. It is relatively stable and resistant to transient pressure. Because it is cast, cord tunnels and detonator wells are an integral part of the booster. To assemble primer using a cast booster and detonating cord, the detonating cord is passed completely through the proper tunnel and a knot is tied in the end securing the booster to the detonating cord. When a detonator is used, the detonator is pushed through the detonating cord tunnel and then inserted into the capwell (Figure 6.4).

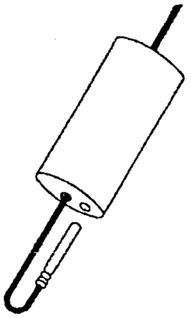


Figure 6.4

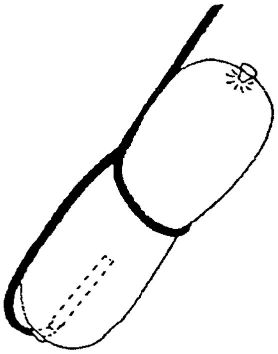
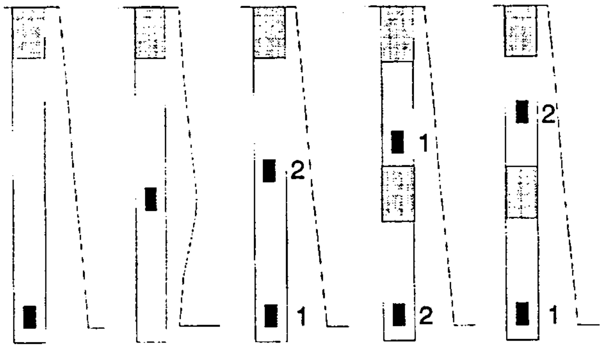


Figure 6.5

Often dynamite and other cartridge explosives are used as boosters. They are prepared by punching a hole into one end (using a punch made of non-sparking material), pushing the detonator all the way into the punched hole. The detonator is secured to the cartridge by half hitching the leg wires, shock tube, or low energy detonating cord around the cartridge (Figure 6.5). Tape may be used in place of the half hitches to secure the detonator.

Primer location within the blast hole is important for both safety and blast efficiency. As a general rule of thumb, the primer should be placed at the point of most confinement or the most difficult to break (Figure 6.6). In most cases this is the bottom of the hole where the distance to the open face and bench surface is the greatest. If the geology has both soft and hard seams, the primer should be placed in a hard seam area. If the hole has a heavily burdened area, the primer should be located in that area of the hole. If holes are decked, the primers should be located to insure proper confinement and minimal disturbance based on the deck initiation sequence. Deep blast hole, blast holes containing water, and holes intersecting fault areas, should be multi-primed to insure complete column initiation.

PRIMER LOCATION



GENERAL RULE OF THUMB:
LOCATE AT POINT OF MOST CONFINEMENT

Figure 6.6

In small diameter blastholes, the primer is placed in the hole first, detonator pointing toward the hole collar. The primer must not be cut, deformed or tamped. In bench blasting, normal primer position is near the bottom of the hole. Where subdrilling is used, the primer should be placed at the toe level, rather than at the bottom of the hole, to reduce ground vibrations. Top priming is seldom recommended except where the only fragmentation difficulty is a hard band of rock in the upper portion of the bench.

LOADING

Loading involves putting the primers, main charge, any deck charges and stemming in the holes in a manner described in the blasting plan. Loading techniques vary depending on the hole diameter, type of explosive, the geology, and equipment available. The blaster should supervise all of the work to insure all of the explosives are handled and used in a proper and safe manner. There should be good communication between the blaster and rest of the blast crew as to specific loading procedures and sequence. The blaster and crew should be familiar with the recommendations in the "Warnings and Instructions" pamphlet included with the explosives.

In normal loading, the primer charge is inserted in the blasthole first. If packaged product is being used for wet conditions or toe loads in a large diameter hole, one package is placed in the hole prior to inserting the primer cartridge. The main charge is then loaded into the blasthole using either bulk or packaged explosives.

Bulk products are either augered, pumped, poured, or blown into the blasthole. In large mining operations bulk explosives are usually preferred. Bulk explosives are easier to handle, load faster, totally couple, usually less expensive, and do not have packaging disposal requirements. Stored in bins and silos, bulk products can be transferred to bulk delivery trucks with minimal time and labor. Modern bulk trucks are available that deliver ANFO, emulsion, and slurry to the blast site in the same truck. Each product can be loaded individually or in combination with the other products into the blasthole. This allows the blaster to field blend the explosive density, velocity, or water resistance to the field conditions he encounters. Bulk truck capacity is nominally from 1 to 15 tons. Delivery rates range up to 600 pounds per minute augered and 400 pounds per minute pumped.

Packaged products are often used in wet holes, for high energy toe loads, and for small diameter blastholes. They are lowered, dropped or pushed into place with a tamping pole or loading hose. In general, best blast results are achieved where the explosive charge completely fills the diameter of the blasthole. By being in contact with the blasthole walls or totally coupled, the explosive energy will produce its maximum efficiency. Bulk loaded explosives provide good coupling. When cartridged products are used, coupling is improved by slitting the cartridges and tamping them firmly into place. There are four conditions where cartridges or packages should not be tamped or slit:

1) in permissible coal mine blasting where it is against regulations,
2) in controlled blasting,
3) in water, where the package serves as protection, and
4) when use as a primed cartridge.

As the main charge is introduced into the blasthole, its level should be constantly monitored to prevent overloading of holes. A weighted tape is recommended. When the explosive column reaches the proper level, an additional primer, deck, or stemming may be added. It is important that each phase of loading and explosive positioning be accurate.

Care must be taken during loading to insure initiation legwires or downlines are not damaged or lost down the hole. These should be extended and properly secured at the borehole collar using a rock or stake. Prior to adding stemming to the hole electric detonators should be checked for continuity and non-electric initiation should be visually inspected for possible damage during the introduction of the explosive. If problems are suspected, another primer should be inserted prior to stemming.

After explosive loading has been completed, blastholes should be stemmed to confine the explosive energy, and minimize the potential of airblast and flyrock, thus improving blast efficiency. Typical stemming is about 0.7 times the burden and usually consists of crushed stone or drill cuttings. Sized, angular, crushed stone makes the most efficient stemming. Blastholes containing water should utilize crushed or sized stone for stemming, since drill cuttings mix with water and do not provide proper confinement and may allow column separation. Large rocks should not be used for stemming as they may contribute to flyrock or may damage the initiation legwires or downlines. After the holes are stemmed, the blaster should make sure all left over explosives and empty packaging materials are removed from the blast site before initiation system hook-up begins.

If delays in loading have resulted in an inability to detonate the blast in accordance with the blasting schedule and the blast must wait until the following day, the surface initiation should not be conneceted. Also the blast bench must be guarded and protected with at least one person present at all times.

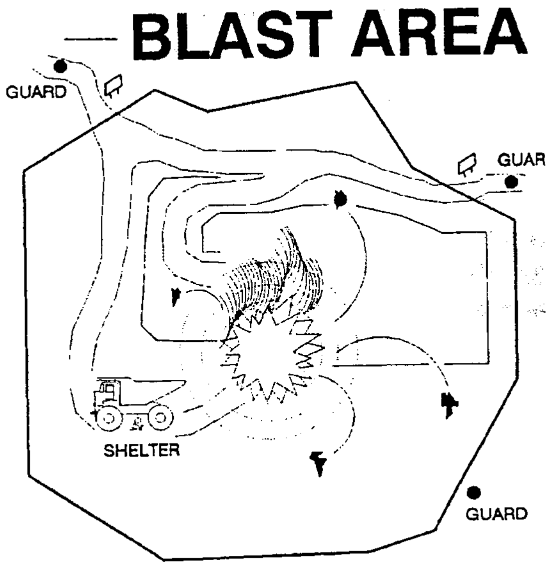
The hole to hole hookup of the initiation system is critical for the successful detonation of the blast. Improper initiation hook up and checking is the leading cause of blast misfires. The size of the crew used to hook up the initiation system should be kept to an absolute minimum. The blaster should be in charge of the final checkout to assure the initiation plan has been properly followed and the round is ready to detonate. The holes should be connected in the proper order to facilitate checking and testing as each series is completed. All splices and connections should be made properly as discussed in Chapter 2. Non-electric initiation systems should be connected and checked according to the recommendations from the manufacturer. If the initiation components requires covering, this should be done after the circuit is visually checked.

After all the holes have been properly hooked up and checked, the blaster should make final visual inspection of the blast site to make sure that none of the loaded holes have been missed and that no other problems or oversights exist.

BLAST DETONATION PROCEDURES

When the blaster is satisfied that the blast is ready to detonate, he should notify the foreman or other person in charge. The blast should be detonated as soon as possible after holes are loaded and the area is cleared and secured. If the blasting plan specifies times at which the blast can be detonated, then the loading schedules should be arranged accordingly.

The operation should establish standard procedures for clearing the blast area (Figure 6.7) of all non-essential personnel, animals, and equipment, posting of security guards to prevent entry into the blast area, and accounting for all employees, visitors, and equipment. All employees and visitors must be familiar with these procedures. The foreman or other person in charge should implement these procedures after notification by the blaster.



Definition: CFR 30, 56 & 77

The area in which concussion (shock wave), flying material, or gases from an explosion may cause injury to persons.

Figure 6.7

Once all equipment and personnel in the vicinity of the blast bench are removed, the blaster should lay out his firing line. Safety rules to remember are:

Electric initiation

(1) Use only single strand insulated copper wire lead lines, preferably 12 or 14 gauge or approved sequential timer firing cable. Minimum length of firing line is 450 feet. When popping coal firing line must be at least 100 feet long.

(2) Be sure that wire connections are bright, tight, and clean.

(3) Do not load boreholes near electric power lines unless the length of the firing line, plus the length of the cap leg wires, is short enough that they would not contact the power lines if thrown into the air during the shot.

(4) Federal regulations prohibit firing lines from being closer than 20 feet from powerlines.

(5) Do not lay out firing line until just before you are ready to hook up and detonate the blast.

(6) Spool out firing line by walking. Do not spool out firing line from truck or other vehicle.

(7) Firing line must be kept disconnected from power source and shunted until ready to fire.

Non-electric initiation

(1) Do not connect firing line to blast until all personnel and equipment are outside of blast area.

(2) Insure any connections or splices are water proof, secure, and made per manufacturer's recommendations

(3) Do not lay out firing line until just before you are ready to hook up and detonate the blast. Minimum length of firing line is 450 feet., 100 feet for coal popping.

(4) Spool out firing line by walking. Do not spool out from truck or other vehicle.

(5) Do not stretch or stress firing line

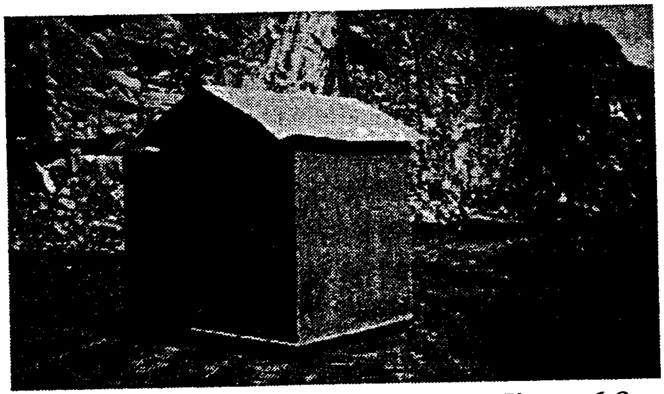
(6) Do not connect firing device to firing line until you are ready to detonate the blast.

After the blast area is cleared and secured, and the firing line has been run, the blaster again notifies the foreman or person in charge that he is ready to fire the blast. When the foreman or person in charge notifies the blaster that everyone is clear of the blast area and accounted for, and the blaster is now in control of the blast, the blaster or person designated by him will sound the blast warning signal. The warning signal is mandatory and shall conform to WVDEP regulations.

The warning signal shall be sounded 3 minutes prior to blast detonation and be audible for a range of one-half mile in all directions. This pre-blast warning shall consist of three (3) short blasts of five (5) seconds duration, with five (5) seconds between each blast. One (1) long audible warning signal of twenty (20) seconds duration shall be the "all clear" signal.

During the three minute period between the warning signal, the blaster should visually check to insure the pit and immediate blast area is clear. If electric initiation is being used, he should perform a circuit check before connecting the firing line to the blasting machine. If he is using a non-electric initiation system, he should arm the initiation device. Actual connection of the firing line to the blasting machine or initiation device should not be done until a time just before detonation is to occur.

The certified blaster shall be accompanied by at least one other person at the time of the blast detonation. The blaster and anyone accompanying him should choose a safe firing location under cover (Figure 6.8) which affords protection from flyrock and concussion. The location should also have a good view of the surrounding area. The blaster should receive a positive response from each guard just prior to activating the firing mechanism and initiating the blast. If for some reason the blast fails to fire, security must be maintained while the blaster attempts to correct the problem.



Blast Shelter Figure 6.8

After the blast is detonated, the firing line is immediately disconnected from the firing device and for electric initiation, shunted. The blasting machine or other firing device is then secured. The blaster should stay under shelter for a minute or two to allow any flyrock to drop and fumes and dust to disperse. The blaster inspects the blast site looking especially for evidence of misfires, unexploded materials or the burning of explosive materials in a hole or the muck pile. A check should also be made for any loose rock, backbreak, overhangs or other unstable conditions. Other personnel must not be permitted into the area until it is certain that no hazards exist. Security must be maintained until these checks are made and the "all clear" signal has been sounded by the blaster. The "all clear signal consists of one long 20 second blast on the warning signal device.

MISFIRES

A misfire is the failure of an explosive charge or a portion of an explosive charge to detonate at the proper time. Every precaution should be taken to prevent the occurrence of a misfire. Whenever misfired holes, parts of misfired holes, or undetonated explosive materials remain after a blast is detonated, a hazardous condition exists. Blast area security must remain in place until after the misfired condition is corrected. The foreman or person in charge is notified of the misfire to insure no unauthorized personnel enter the blast area. In the event of a known or suspected misfire, a waiting period of at least 15 minutes (30 minutes with cap-and-fuse blasting) must be observed. If explosives are burning or suspected to be burning in a borehole, the minimum waiting period is one hour.

There are many things that cause explosives to misfire. They can be broken down into several general groups: poor blast design and planning, improper loading procedures, improper product application, improper connection of initiation system (failure to connect, cutoffs, or current leakage), desensitized or interrupted powder column, old product, or malfunctioning explosive component. Human error is the causes of most misfires. Failure to follow standard procedures, taking short cuts and rushing to achieve a time requirement often result in misfires. Remember, there is a difference between standard procedures and accepted procedures. Do not accept a procedure just because it has been done for years. Products and regulations change. Consult your manufacturer concerning proper procedures, if you are unsure.

Some clues that indicate that a misfire may exist are: a portion of the blast and its initiation system undisturbed, loose explosives on the muck pile, poor fragmentation and improper rock displacement, a low roaring sound caused by burning explosives, the sound and vibration pattern during the blast, and the gut feeling of the experienced blaster. Many blast bench conditions can contribute to misfires. The experienced blaster can identify these, design proper blast designs to handle them, and will use them as a guage to judge the success of the blast.

When a misfire occurs, the power source used to fire the blast must be disconnected and made safe (shunt electric circuits). Federal, state and local regulations govern the handling of misfires. The disposal of misfires should be done only by experienced persons familiar with the explosive materials and initiating systems involved in the blast. He should also know and understand the proper techniques for handling, neutralizing and disposing of the materials in a safe manner (Figure 6.9). Every misfire must be evaluated on an individual basis.

After the waiting period, the blaster inspects the area using the appropriate methods and test instruments to check all observable initiation system components. He also does a visual inspection of the blast area for exposed explosive materials in the muck pile. Using his experience and knowledge from other experienced persons with whom he may consult, the blast must develop a plan to remove the misfire hazard. Although every misfire is different, there are three basic methods for handling misfires. In the order of preference, they are:

(1) If sufficient burden exists and the initiation system is still intact or can be repaired or replace, the misfired explosive charges are reconnected and detonated. It should be noted that detonating misfires has a high potential for flyrock and airblast. Extreme safety precautions, such as enlargement of the blast security area, should be undertaken when detonating misfired explosives.

(2) The misfired explosives charges are removed form the blastholes. Stemming is flushed out by water and ANFO neutralized by water, emulsions, blends and slurries flushed out with water or packaged explosives removed with a non-sparking retrieving tool.

(3) Drill, load and detonate blastholes adjacent to the misfire and remove the misfired explosives by excavation. These actions are extremely hazardous and should only be considered as a last resort. A spotter should be used for any excavation of a misfired shot. Excavation should cease when any undetonated explosive is seen. The explosive should be removed before excavation continues.

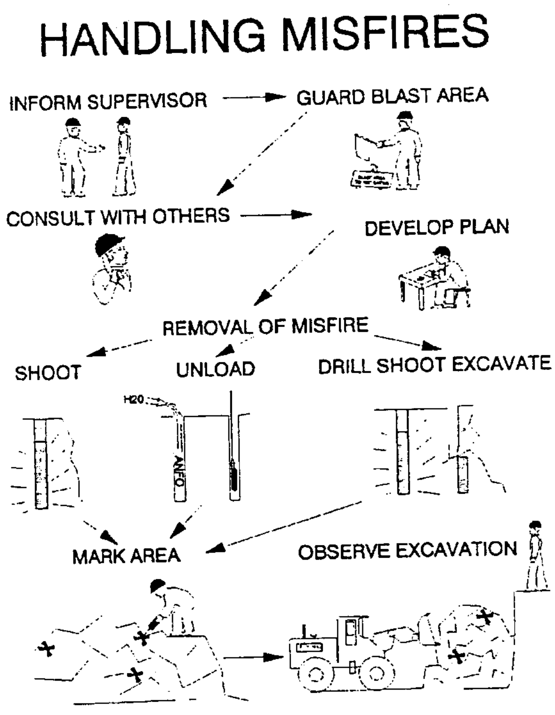


Figure 6.9

The disposal of misfires or the working of personnel and equipment in areas where misfires are present is extremely hazardous and only competent, experienced persons should be involved.

A complete examination of every blast for the presence of misfires is extremely important. It is the blasters responsibility to insure that no misfired explosives create an unsafe work environment for his fellow workers. This includes drillers, excavators, haulers and processing operators. Drilling into explosives is one of the most frequent causes of blasting accidents. The best way to eliminate drilling accidents involving explosives is to insure that misfires do not occur.

DISPOSAL OF EXPLOSIVE MATERIALS

Under no circumstances should misfired explosives, or explosives subject to adverse environment be used. The recommended method for disposing of explosives for many years was burning. However under new EPA Regulations, this is no longer the true. The blaster and or the blaster's supervisor should consult with their explosive supplier to determine how to best dispose of the unwanted explosive under current laws.

SECONDARY BLASTING

Even well designed blasts sometimes leave boulders that are too large to be handled efficiently by the available equipment. Secondary fragmentation methods are used to break these boulders. There are basically four methods of doing this:

1. A heavy ball suspended from a crane (often referred to as a dropball) may be dropped repeatedly on the boulder until it breaks.
2. A hole may be drilled into the boulder and a wedging device inserted to split it.
3. Loose explosive is sometimes placed in a crack or depression in the boulder, covered with damp earth (or mud) and detonated. This is called a mudcap, plaster or adobe charge. This is inefficient, requires relatively large amounts of explosive and results in considerable noise and flyrock. This method is hazardous and should be used only when it is not practical to drill a hole into the boulder.
4. The most efficient method of secondary fragmentation is by drilling one to three inch diameter holes into the boulder and loading with explosives. The hole is directed towards the center of the boulder and is drilled 2/3 to 3/4 of the way through the rock. A powder factor of .25 lb/yd^3 is usually sufficient. When in doubt, it is better to estimate on the low side and underload the boulder. With large boulders, it is better to drill several holes and distribute the charge rather than putting it all in the same hole. All holes should be stemmed. Electric blasting is frequently used and where noise is not a problem, detonating cord is often used.

Although secondary blasting uses relatively small charges, its potential hazards must not be underestimated. Flyrock is often more severe and difficult to predict. Secondary blasts require at least as much care in warning and guarding as do primary blasts and experience is an important element for success.

CHAPTER 7
EXPLOSIVES HANDLING

TRANSPORTATION

The movement of explosive materials over public highways is controlled by Department of Transportation (DOT) regulations and local and state regulations. Although these regulations do not apply to transport on non-public roads (mine roads, quarry property, etc.), they still form a good basis for the safe transportation and delivery of explosive materials to the blast site.

As discussed in Chapters #1 and #2, explosives are classified by their sensitivity: high explosive, low explosive and blasting agent. In the past DOT classified explosives by sensitivity and quantity, Class A, Class B, Class C, and Blasting Agent. Because of international transportation requirements, DOT has dropped this classification and adopted the more detailed United Nations Classification System. Although it is not applicable on mine property, it can provide the blaster with a method of classifying the explosives he is transporting and storing. Most commercial explosives used in surface mining are classified as either 1.1B (high explosive), 1.1D (high explosives) 1.4B (high explosive, limited quantity) or 1.5B (blasting agent). Details of the UN classification system can be found in Appendix E.

In transporting explosives on mine property, certain vehicle and procedural criteria must be met. The criteria for vehicles used to transport explosives may be summarized as follows.

A vehicle used to transport explosives:

(1) Needs to be maintained in good condition.
(2) Must be solidly constructed.
(3) Must be lined with wood or approved non-sparking material with no sparking metal exposed.
(4) Needs suitable sides and tailgate.
(5) Has to be posted with proper warning signs indicating it is being used to transport explosives.
(6) Must have a four inch hardwood (or equivalent) partition to keep detonators separate from explosives.
(7) Needs to carry a five pound (or larger) portable multipurpose dry chemical fire extinguisher at all times.
(8) Must have electrical wiring that is adequately protected and securely fastened.
(9) Must be kept reasonably clean (free of gas and oil).
(10) Cannot have leaking fuel tanks or lines.
(11) Must have light, horn, brakes, windshield wipers and other appropriate safety devices in good working order.

The following safety rules must be practiced:

(1) Drive slowly and carefully and maintain safe operating practice.
(2) Properly secure tools placed in the cargo area.
(3) Do not place tools made from sparking material in the cargo area containing any explosive materials.
(4) Transport explosives promptly. Do not delay.
(5) Transport explosives along the route which will pass by the least number of people.
(6) Only necessary workers should ride in the vehicle.
(7) Always stay with the vehicle when it is loaded with explosives.
(8) Do not load explosives or blasting agents higher than the sides or tailgate of the vehicle.
(9) Set the brakes and shut off the motor when parking the vehicle .
(10) Always block the wheels to prevent the vehicle from rolling when stopped.
(11) Unload all explosives, caps, detonating cord and blasting agents before taking the vehicle into a repair garage or shop.
(12) Repair or replace any damaged wire immediately.

EXPLOSIVE STORAGE

All explosives, blasting agents, detonators and initiating devices must be stored in magazines that have been constructed, approved and licensed according to local, state and federal regulations. The magazines must be kept locked except when explosive materials are being delivered or removed. Admittance to the magazine should be restricted and only those authorized should have keys.

The Bureau of Alcohol, Tobacco and Firearms (BATF) and the West Virginia Fire Marshal regulate explosives distribution and storage. As discussed in Chapter #8 this includes proper record keeping. Safe storage of explosives in the mining industry, including BATF regulations, is enforced by the Mine Safety and Health Administration (MSHA), the West Virginia Fire Marshal's Office, and the Division of Environmental Protection. Their rules govern the location, lighting and maintenance of magazines.

Storage magazines for high explosives must be well ventilated, resistant to bullets, fire, theft and weather. Federal requirements for blasting agents are less stringent and they need only be theft resistant. All explosives, blasting agents and initiators must be stored in magazines that have been constructed, approved and licensed according to local, state and federal regulations. They must be kept locked at all times except when loading or removing material and admittance should be restricted to those authorized to enter .

There are five (5) types of magazine storage (Figure 7.1). Type 1 is a permanent storage facility for storing high explosives. Type 2 is a portable storage facility for storing high explosives. Type 3 is a "day box" for storing high explosives for periods less than 24 hours. Type 4 is a permanent or portable facility used for storage of detonators, propellants and blasting agents. Type 5 magazine is a building, bin, tank, or semi-trailer used for storage of blasting agents. Details on magazine construction and storage can be found in the BATF Regulations.

Magazines must be:

(1) Detached structures located 100 feet away from powerlines, fuel storage area, and other possible sources of fire
(2) Constructed substantially of non-combustible material or covered with fire-resistant materials
(3) Bullet resistant (types 1 and 2)
(4) Electrically bonded and grounded if constructed of metal
(5) Lined with non-sparking materials, including floors
(6) Provided with adequate and effectively screened ventilation openings near the floor and ceiling
(7) Kept locked securely with two padlocks when unattended
(8) Posted with appropriate warning signs located so a bullet passing through the sign will not strike the magazine
(9) Used only for storage of explosives or detonators and kept free of any other materials
(10) Kept clean and dry on the inside and in good repair
(11) Unheated, unless heated in a manner that does not create a fire or explosion hazard
(12) Provided with doors constructed of a steel plate at least 1/4 inch thick

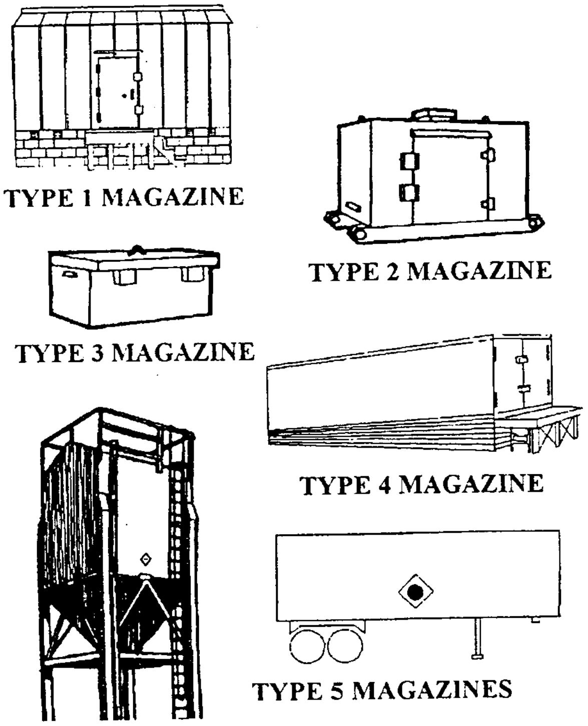

TYPE 1 MAGAZINE
TYPE 2 MAGAZINE
TYPE 3 MAGAZINE
TYPE 4 MAGAZINE
TYPE 5 MAGAZINES

Figure 7.1

The safety rules to be followed when working in and around magazines are:

(1) Keep detonator storage magazines at least 25 ft. away from explosive storage magazines
(2) Keep a 25 ft. area around the magazine free of dry leaves, grass, undergrowth, trash, or debris
(3) Do not stack cases or boxes of explosives on their sides or ends
(4) Do not stack cases or boxes of explosives more than 6 feet high
(5) Separate ANFO type blasting agents from explosives, safety fuses or detonating cord so that leaking oil will not desensitize or contaminate the other explosive
(6) Do not store primers, water gels, and other high explosives or blasting agents in the same magazine as detonators
(7) Do not smoke within 50 ft. of a magazine;
(8) Do not unpack or repack damaged or deteriorated explosives within 50 feet;
(9) Do not store detonating cord or low energy detonating cord in the same magazine with detonators
(10) Consult the American Table of Distances (Appendix F) to determine the proper location of magazines from areas of public access or inhabited buildings.

(11) Explosive stock should be rotated such that the oldest material is used first (FIFO - first in first out)
(12) Old or damage explosives should not be used. They should be destroyed in compliance with EPA regulations, State and local requirements, and in conjunction with manufacturer recommendations.

CHAPTER 8
RECORD KEEPING

In today's operating climate of regulatory compliance, litigation, terrorism, crime, and tight operating budgets, it is imperative that good record keeping be maintained in the accountability, security and application of explosive products. Two such documents required by West Virginia law are Inventory Records and Blasting Logs.

INVENTORY

Inventory records are written documentation of all explosives received, stored and used. The certified blaster is responsible to insure that inventory records are kept current and retained on file for a period of five (5) years. All records must be available for inspection.

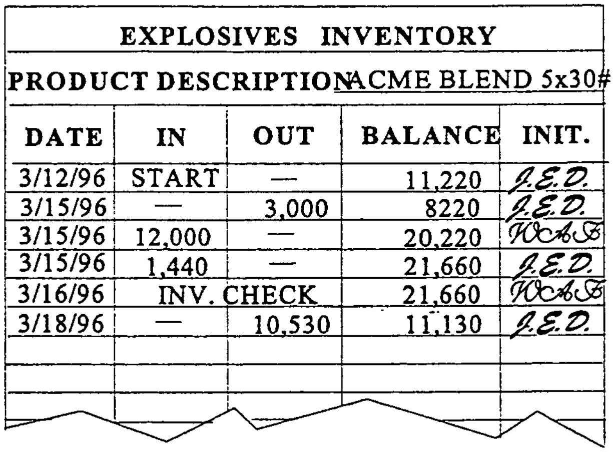
A company or person holding a "Permit to Blast" must keep a daily record of all explosives received, detonated, returned or disposed of in any way. Regulations require that these daily records be kept by the person or company holding the "Permit to Blast." Because the certified blaster is normally the individual removing and replacing explosives in the magazine, day-to-day magazine inventory records are his responsibility, unless otherwise documented in writing by his company. Failure to keep accurate inventory records could result in loss of Blaster Certification.

For operations where explosives are not stored on site but are delivered on a day-to-day basis by the explosive supplier, inventory records are not required. It is recommended that all invoices, sales slips, delivery tickets or similar papers recording explosives received be retained. These papers must contain the signature of the person who received the explosives.

The actual format of the inventory record form can be determined by the company or person holding the "Permit to Blast". At a minimum, the inventory record must contain an entry for the date, explosive type, explosives received, explosives removed, balance on hand, and initials of person making entry. A sample inventory record (Figure 8.1) and an explanation of how complete these records follows:

- o An inventory sheet, like the example in Figure 8.1 is used for each type of explosive and detonator to be stored in the magazine. The combination of all these sheets are kept to reflect the explosive inventory.
- o The product name and description should be entered at the top of the inventory sheet
- o Line 1: The date and the starting balance are entered on the first line. The starting balance may be a balance brought forward from a previously filled inventory sheet. The person making the entry must initial the line.

- Line 2: Example indicates explosives removed from the magazine for the day's blast. Entry is date, amount removed, balance, and initials of person making entry.
- Line 3: Example indicates explosives delivered by supplier during shift. Entry is date, amount added, balance, and initials of person making entry.
- Line 4: Example indicates excess explosives removed earlier for the day's blast returned to the magazines after loading. Federal law requires all unused explosives be promptly returned to trailers or magazines. Entry is date, amount added, balance, and initials of person making entry.
- Line 5: Example indicates that a physical inventory check was conducted of the magazines contents. Entry is date, "INV. CHECK", balance, and initials of person making entry.



EXPLOSIVES INVENTORY

PRODUCT DESCRIPTION ACME BLEND 5x30#

DATE	IN	OUT	BALANCE	INIT.
3/12/96	START	—	11,220	J.E.D.
3/15/96	—	3,000	8220	J.E.D.
3/15/96	12,000	—	20,220	W.A.S.
3/15/96	1,440	—	21,660	J.E.D.
3/16/96	INV. CHECK		21,660	W.A.S.
3/18/96	—	10,530	11,130	J.E.D.

Figure 8.1

- Line 6: Example indicates explosives removed from the magazine for the day's blast. Entry is date, amount removed, balance, and initials of person making entry.
- Succeeding lines will each reflect an addition, deletion or physical inventroy of the explosive stored in the magazine. The balance on the last line indicates the amount of that explosive currently on hand in the magazine.

The inventory record must be initialed by the certified blaster or company representative responsible for inventory control.

If a permit holder changes address, the issuing authority must be notified promptly.

If explosives are lost, stolen or unlawfully removed, the permit holder must notify the following agencies within 24 hours:

1) Director-Bureau of Alcohol, Tobacco and Firearms, U.S. Department of the Treasure (1-800-424-9555),
2) Issuing authority (for example, your explosive dealer).
3) Local police

Explosives and their performance may deteriorate with age. It is recommended that those products delivered and stored first be used first (FIFO first in, first out). Good inventory control will assist in proper stock rotation.

BLASTING LOGS

Blasting Logs are a written record containing the details of how a blast was designed, loaded and detonated. It may also document the consequences of the blast such as fragmentation, vibration, airblast, flyrock, etc. Because a blasting log may be used to troubleshoot problems, determine blasting efficiency, train new blasting personnel, and as a defense in court, it should be contain as much detail as possible.

State regulations describe the required contents and circumstances for keeping a blasting log record. Each blasting log must contain all the information listed below:

1. Name of permittee, and permit number.
2. Location, date and time of the blast.
3. Name, signature and certification number of the blaster.
4. Direction and distance, in feet, to the nearest dwelling, school, church or commercial institution, neither owned nor leased by the operator.
5. Weather conditions.
6. Type of material blasted.
7. Number of holes, burden and spacing.
8. Diameter and depth of holes.
9. Types of explosives used.
10. Total weight of explosives used.
11. Maximum weight of explosives detonated in any eight ms period.
12. Method of firing and type of circuit.
13. Type and length of stemming.
14. If mats or other protection were used.
15. Type of delay detonators used and delay periods.
16. Seismograph records, where required, including, but not limited to:
    a. Seismograph reading, including exact location of seismograph and its distance from the blast,
    b. Instrument calibration date,
    c. Name of person taking the seismograph reading, and
    d. Name of person and firm analyzing the seismograph record.
17. The shot location.
18. Reason and conditions for an unscheduled blast
19. A sketch of the blast delay pattern layout
20. Comments of significance

An official West Virginia blasting log record is shown in Figures 8.2A and 8.2B.

Blasting logs must be completed for every blast and must be kept at the mine site for three (3) years. It is the responsibility of the certified blaster to properly complete a blasting log for each blast and to maintain the files. The blasting logs are subject to routine inspection by the West Virginia Division of Environmental Protection.

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Rev. 02/04

State of West Virginia
Department of Environmental Protection - Office of Explosives and Blasting

Shot No.______

BLASTING LOG

General Information

Permittee ________________ **Permit No.**__________
Operator Name ________________ **Date/Time** __________
(Approved MR-19 Contract Operator, if applicable)
Company Conducting Blast ________________
(Contract Blaster i.e.; Shot Service, if applicable)
Location of Blast ________________
(Specify grid designation from blasting grid map, GPS location if available, and type of shot.)
Nearest Protected Structure ________________
(Specify name of homeowner/structure owner and structure number from blasting map)
Direction and Distance to Nearest Protected Structure *(Feet)* ________________
Nearest Other Structure ________________
(Specify name of owner, identifying no., describe i.e.; gas well, gas line, power line, phone line, water line, barn, etc.)
Direction and Distance to Nearest Other Structure *(Feet)* ________________
Weather Conditions ________________**Wind Direction and Speed** ________________
(Include estimated temperature, precipitation, sky conditions, speed and direction wind is blowing from shot)
Type(s) of Material Blasted ________________
Mats or Other Protection Used ________________

Blast Information

Type(s) of Explosives: Blasting Agent ________________ Density__________
(Include percent blend of emulsion to anfo) *(Product density in g/cc)*
High Explosives (Primers) *(Include type, unit weight and number)* ________________
Total Weight of Explosives: Blasting Agent __________lbs. + Primers __________lbs. = __________lbs.
Blast hole Data: Number ______ Diameter ______ Depth ______ Burden ______ Spacing ______
(For varying hole depth, diameter, stemming, burden and/or spacing, list additional data in 'Comments' and illustrate on 'Sketch' on Page 2)
Powder Column ______ft. **Stemming:** Type of Material ________________ Length __________ft.
Delay Type, Brand and Delay Periods ________________
(Include surface and down hole delay periods)
Maximum Weight of Explosives Allowed (per 8 MS Delay Period) ________________lbs.
[Show appropriate formula and answer for: 0-300 ft. $W=(d/50)^2$, 301-5,000 ft. $W=(d/55)^2$ or Over 5,000 ft. $W=(d/65)^2$]
Maximum Weight of Explosives Used (per 8 MS Delay Period) ________________lbs.
Weight of Explosives Used per Hole/Deck ________________lbs.
(If not the same for every hole/deck, include each weight or average weight and explain)
Method of Firing and Type(s) of Circuits ________________

Seismograph Data

Date and Time of Recording from the Seismogram: ________________
Type (Brand and Model Number) of Instrument: ________________**Sensitivity:** __________Hz.
Person and Company Who Installed Seismograph: ________________
Person and Firm Taking Readings: ________________
Person and Firm Analyzing Readings: ________________
(Attach full waveform seismograms, for all seismograph recordings for this blast. Include calibration signal even if no trigger)
Signature of Person Analyzing Readings: ________________
Location of Seismograph: ________________
(Specify owner's name and structure number from the blast map, including distance from blast)
Trigger Levels: Ground: __________ips **Air:** __________dB **Length of Recording Time:** __________sec.
Vibrations Recorded: Longitudinal: ________**Transverse:** ________**Vertical:** ________ **Air Blast:** ________
Frequency: Longitudinal: ________ Hz. **Transverse:** ________ Hz. **Vertical:** ________ Hz. **Air Blast:** ________ Hz.
Certificate of annual calibration must be maintained at the mine site.

Form available at www.wvdep.org

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Shot No.____________
Date/Time ___________
Permit No.___________

Sketch of Delay Pattern

Show North Arrow & Direction to Nearest Protected/Other Structure. Include Firing Time for Each Hole or Deck.

Comments

Include any special design features, such as decking (use sketch), variable hole depth, etc., reasons and conditions for unscheduled blasts and any unusual events or circumstances (i.e.; flyrock, excessive air blast or ground vibration, etc.). Include attachments as needed.

____
____
____
____
____
____
____
____

Blaster Information

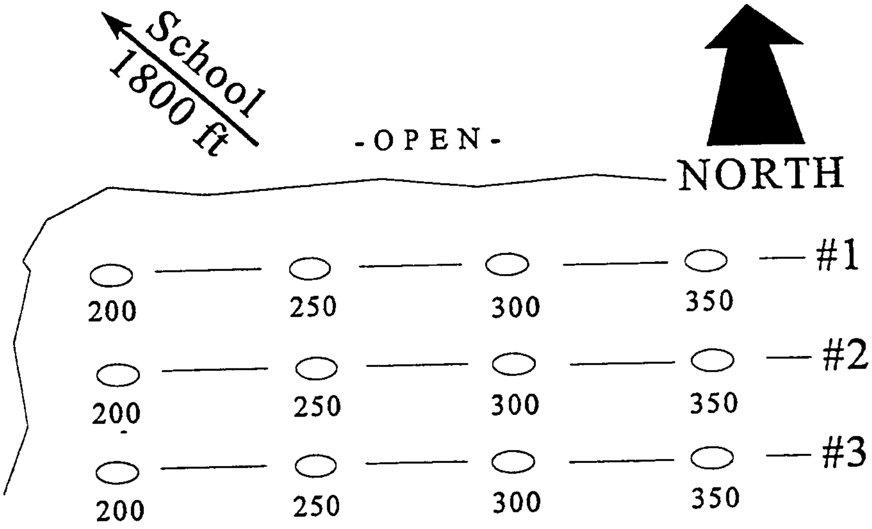
Name of Blaster-in-Charge (Print or Type): ______________________________

Signature of Blaster-in-Charge: ______________________________
WVDEP-OEB Certification Number of Blaster-in-Charge: ______________________________

Form available at www.wvdep.org

Example Problem

You are a certified blaster for the D. O. E. Mining Company; your license number is 87-152. You are working on Permit No. S-100-86. You have loaded twelve (12) holes, 6 3/4 inches in diameter and 50 ft. deep. Holes are drilled on a pattern with a burden of 16 ft., and a spacing of 16 ft. The driller's log says you are shooting sandstone and shale. You have loaded each hole with ten 50-lb. bags of ACME ANFO, and one l-lb. ACME cast primer. This leaves 12 ft. which you stem with crushed rock. The blast is located on the grid map at H-7. The closest structure is a school located 1,800 ft. northeast of the blast, and a seismograph is not used. The weather is 98"F and sunny, with the wind direction from the southwest at 5 miles per hour. No mats or other protective devices are used. The shot is fired at 11:30 a.m. on October 6, 1995. You are using a sequential timer set on 20 ms delay between series. The shot consists of 3 rows with 4 holes per row. There is one ACME 200 ms delay detonator, one 250 ms delay detonator, one 300 ms delay detonator, and one 350 ms delay detonator in each row. Each row is connected into a series and row 1 is connected to circuit 1, row 2, circuit 2 and row 3, circuit 3.



Timer Setting 20 ms

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Rev. 02/04

State of West Virginia
Department of Environmental Protection - Office of Explosives and Blasting

Shot No. ______

BLASTING LOG

General Information

Permittee ______________________ **Permit No.** __________
Operator Name ______________________ **Date/Time** __________
(Approved MR-19 Contract Operator, if applicable)
Company Conducting Blast ______________________
(Contract Blaster i.e.; Shot Service, if applicable)
Location of Blast ______________________
(Specify grid designation from blasting grid map, GPS location if available, and type of shot.)
Nearest Protected Structure ______________________
(Specify name of homeowner/structure owner and structure number from blasting map)
Direction and Distance to Nearest Protected Structure *(Feet)* __________
Nearest Other Structure ______________________
(Specify name of owner, identifying no., describe i.e.; gas well, gas line, power line, phone line, water line, barn, etc.)
Direction and Distance to Nearest Other Structure *(Feet)* __________
Weather Conditions ______________ **Wind Direction and Speed** __________
(Include estimated temperature, precipitation, sky conditions, speed and direction wind is blowing from shot)
Type(s) of Material Blasted ______________________
Mats or Other Protection Used ______________________

Blast Information

Type(s) of Explosives: Blasting Agent ______________ **Density** __________
(Include percent blend of emulsion to anfo) *(Product density in g/cc)*
High Explosives (Primers) *(Include type, unit weight and number)* ______________
Total Weight of Explosives: Blasting Agent ________ lbs. + **Primers** ________ lbs. = __________ lbs.
Blast hole Data: Number ______ **Diameter** ______ **Depth** ______ **Burden** ______ **Spacing** ______
(For varying hole depth, diameter, stemming, burden and/or spacing, list additional data in 'Comments' and illustrate on 'Sketch' on Page 2)
Powder Column ______ ft. **Stemming: Type of Material** ______________ **Length** ______ ft.
Delay Type, Brand and Delay Periods ______________________
(Include surface and down hole delay periods)
Maximum Weight of Explosives Allowed (per 8 MS Delay Period) ______________ lbs.
[Show appropriate formula and answer for: 0-300 ft. $W=(d/50)^2$, 301-5,000 ft. $W=(d/55)^2$ or Over 5,000 ft. $W=(d/65)^2$]
Maximum Weight of Explosives Used (per 8 MS Delay Period) ______________ lbs.
Weight of Explosives Used per Hole/Deck ______________ lbs.
(If not the same for every hole/deck, include each weight or average weight and explain)
Method of Firing and Type(s) of Circuits ______________________

Seismograph Data

Date and Time of Recording from the Seismogram: ______________________
Type (Brand and Model Number) of Instrument: ______________ **Sensitivity:** ________ Hz.
Person and Company Who Installed Seismograph: ______________________
Person and Firm Taking Readings: ______________________
Person and Firm Analyzing Readings: ______________________
(Attach full waveform seismograms, for all seismograph recordings for this blast. Include calibration signal even if no trigger)
Signature of Person Analyzing Readings: ______________________
Location of Seismograph: ______________________
(Specify owner's name and structure number from the blast map, including distance from blast)
Trigger Levels: Ground: __________ ips **Air:** ________ dB **Length of Recording Time:** ________ sec.
Vibrations Recorded: Longitudinal: ________ **Transverse:** ________ **Vertical:** ________ **Air Blast:** ________
Frequency: Longitudinal: ________ Hz. **Transverse:** ________ Hz. **Vertical:** ________ Hz. **Air Blast:** ________ Hz.

Certificate of annual calibration must be maintained at the mine site.

Form available at www.wvdep.org

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Shot No.____________
Date/Time ____________
Permit No.____________

Sketch of Delay Pattern

Show North Arrow & Direction to Nearest Protected/Other Structure. Include Firing Time for Each Hole or Deck.

Comments

Include any special design features, such as decking (use sketch), variable hole depth, etc., reasons and conditions for unscheduled blasts and any unusual events or circumstances (i.e.; flyrock, excessive air blast or ground vibration, etc.). Include attachments as needed.

Blaster Information

Name of Blaster-in-Charge (Print or Type): ____________________

Signature of Blaster-in-Charge: ____________________
WVDEP-OEB Certification Number of Blaster-in-Charge: ____________________

Form available at www.wvdep.org