Construction Blasting Fundamentals

Explosives Defined
An explosive is a compound or mixture of compounds which, when initiated by heat, impact, friction, or shock, undergoes a rapid decomposition, releasing tremendous amounts of energy in the form of heat and gas. This decomposition is a self-propagating, exothermic reaction called an explosion.

Chemically, there are two fundamentally different types of explosive materials: molecular and composite explosives. Molecular explosives are substances that contain all that is needed for reaction within each well-defined molecule. Trinitrotoluene (TNT) and nitroglycerin (NG) are examples of molecular explosives. Composite explosives are mixtures that might contain fuels and oxidizers, and other self-explosive ingredients. Most rock blasting explosives fall into this category, with ammonium nitrate-fuel oil (ANFO) being the classic example. Some composite explosives also contain ingredients such as water or ballast materials that do not add energy to the reaction but modify the mixture's flow properties or consistency. Without exception, composite explosives must contain some mixture of carbon, oxygen, and nitrogen.

Upon detonation, maximum energy release occurs when the explosive mix is formulated for oxygen balance. When explosives are oxygen-balanced, they generally form water vapor (H_2O), carbon dioxide, and nitrogen (N_2). Commercial explosives rarely detonate under ideal conditions, so in actual practice, small amounts of toxic gases—such as oxides of nitrogen (NO and NO_2), carbon monoxide (CO)—are produced.

Explosives Classification
In commercial blasting, explosives and blasting agents are characterized by various properties that define how they will perform under field conditions. These properties include fume class, density, water resistance, temperature effects, detonation velocity, detonation pressure, borehole pressure, sensitivity, and strength.

Fumes are toxic and noxious gases that are produced by the detonation of explosives. Limiting and controlling these gases is most important in underground and confined workings. Factors such as explosive age, water penetration, and chemical reaction with the host rock will affect the amount of fumes produced by an explosive detonation or conflagration.

The density of a material is defined as its weight per unit volume for blasting. Explosive densities are expressed in grams per cubic centimeter (g/cc). Blasters can relate to these metric units because water density is 1 g/cc. Therefore, explosives with densities higher than 1 g/cc will sink in clear water. This is important when blasting in wet areas, where the blaster needs to have the blasting material sink to the bottom of the bore hole.
There are two distinct different reasons for measuring and knowing the relative sensitivity of various explosive compositions. From a safety perspective, it is important to know how sensitive an explosive is to impact, friction, and heat. From a performance

standpoint, measures such as gap sensitivity, critical diameter, and minimum primer sensitivity define the "functional sensitivity" of explosives.

When compared with newer water-based explosives, nitroglycerin (NG) explosives are much more sensitive to detonation by impact or friction. Of the four classes of explosives, NG has the highest sensitivity, followed by high explosive water-gels, ANFO, and then emulsion explosives. NG can be set off by shock, whereas ANFO emulsion blends cannot.

The measure of an explosive's sensitivity determines the minimum size of the primer or detonator that is needed to reliably detonate it under normal conditions of use. The ignition sensitivity varies widely for various explosive types. A blast can be initiated with high-sensitivity explosives by using a detonator. Low-sensitivity explosives, such as ANFO emulsion blends, require a booster (usually a very small amount of high explosives) that is initiated by a detonator to cause an explosion. Obviously, low-sensitivity explosives are safer to use because they cannot be set off accidentally.
When explosives detonate, they produce shock and heave energy. The shock energy is produced in the form of stress waves, driven by the explosive's detonation front. The heave energy is produced by the rapidly expanding gases that follow detonation. Actual explosive yields can be measured by a variety of field tests. The total theoretical energy of explosives can be expressed in calories per unit weight or calories per unit volume. There are other considerations that are important to blasting. One of these is water resistance of the blasting agent, since in many applications explosives are loaded into damp or wet holes. Some blasting agents, such as ANFO, have poor water resistance and will not fire when wet. Temperature levels and fluctuations can affect the stability as well as the performance of explosives.

Whenever possible, contractors typically use ammonium nitrate-fuel oil (ANFO) mix blasting agents for construction blasting. When used properly, ANFO can produce good blasting results with relatively low cost. Number 2 diesel oil is commonly used as the fuel. ANFO can be purchased and handled in either packaged or bulk form. In large scale projects, storing the bulk ingredients requires little special consideration, and loading efficiency is improved by using mechanized systems to handle and load bulk ANFO.

Ignition Systems
Initiating explosives are designed to safely activate larger explosive charges at a controlled time and in a predetermined sequence. Initiating systems are generally classified as electric or non-electric, depending on their signal transmission method. Electric systems use wire to transmit an electric current from a power source to detonators. Non-electric systems use plastic shock tube technology, detonating cords with narrow trains of high explosives, or slow burning pyrotechnic compounds to transmit initiation signals. Blast initiation sequences can be controlled by using timing systems, but delay timing is usually produced by means of pyrotechnic delay elements inside detonators. Delay detonators are available with millisecond or long delays, with approximately ½-second timing intervals.

Long-period (½-second) delays are primarily used in underground blasting applications. For surface blasting, detonators with relatively short-period timing intervals from 25-50 milliseconds (short period) produce the best blasting results. These types of blasts generally produce better rock fragmentation.

Detonators are compact devices designed to safely and efficiently initiate and control the performance of larger explosive charges. They contain relatively sensitive high explosives, which are initiated by a signal or energy from an external source. Delay detonators incorporate components which introduce a controlled time delay to sequence blastholes for optimal results.

The most common initiation system is the shock tube (non-electric) detonator. These convey the signal by a shock front generated by the reaction of powdered aluminum and other chemicals that coat the inside surface of extruded plastic tubes. Field hook-up of modern shock tube units is very easy, and various delay combinations allow for an infinite variety of blasting sequencing. These detonators provide a high level of safety against accidental initiation by static electricity, stray electric currents, and radio frequency energy. They also cannot be initiated by flame, friction, or impact normally encountered in construction blasting operations. The shock tube has been accidentally initiated by stretching the tube until it breaks. If the tube is cut or slit, then a misfire will result, so the tubes must be handled with care.

Blasting Physics and Rock Properties

Commercial explosives release tremendous amounts of energy when detonated. The blast design challenge is to effectively use this energy in the most efficient way to fragment rock in a controlled way. The great energy release of explosive can also cause less desirable effects, such as excessive ground vibration and concussion, overbreaking of the rock, and possible pre-compression failure of the adjacent explosive loads. Blast results may be difficult to predict since they are greatly influenced by the in situ rock conditions. All rocks contain fissures—like bedding planes, partings, and joints—that are opened up by explosion gases and rock movement.

The orientation of structures with respect to blastholes and open faces greatly influence the fracturing process and the potential for overbreak. The heave energy from explosive gases cleaves open the natural joints and bedding planes. When blast direction is parallel to major open joints, potential heave energy is lost when gases prematurely vent to the face through open joints. Jointed or otherwise weakened rock masses can also cause misfires when loaded holes are cut off by premature ground movement and gas penetration. On large projects, it is advisable to perform some small scale test blasts to provide the most complete information about existing rock types, physical properties, structure, and blasting characteristics.

Blasting Design Guidelines

Many interacting factors are involved in the general blast planning process. Blast fragmentation size will influence equipment selection, and visa versa, if equipment already exists. Excavation schedules and drill bench dimensions will influence blast hole

size, explosive selection, and labor requirements. The proximity of blasting to structures can profoundly affect blast planning.

Blasting near structures or urban areas adds a special set of additional concerns. The need for pre-blast structure surveys, vibration and air-blast monitoring, stringent blast effect control measures, and effective blast area security and warning methods must be evaluated for close-in blasting. Geological conditions will also influence blast planning. Physical rock properties and structural conditions will present special blast control challenges.

Bench Layout and Powder Factor

Over the years, bench blast design rules of thumb have been established to help blast designers prepare initial blast designs—or estimators to make preliminary cost estimates—if actual data is not available. These rules of thumb are not intended to predict optimum blast performance. Blast managers should continue to evaluate blast performance to continually improve their design and cost performance. Bench blast design includes the following:

1. Burden calculations
2. Spacing calculations
3. Sub-drill calculations
4. Stemming calculations
5. Inert decking calculations
6. Minimum bench height calculations
7. Load factor and charge weight calculations
8. Powder factor calculations

Drill Pattern and Microsecond Timing

Blast designers have a virtually unlimited variety of drill patterns and hole orientation that they can use to design construction blasts. The drill pattern burdens and spacing are bound by practical limits based on hole size. Large blast holes may be as large as 9 inches or 225 mm. in diameter, while small holes may be as small as 1.5 inches or 38 mm. in diameter. Hole orientation is influenced by project topography, excavation boundary geometry, bench height, bench access, and many other factors. Equipment limitations will also influence hole orientations.

Another factor in blast design is the delayed (millisecond) timing of the initiation of the explosives in relation to one another. Millisecond timing patterns almost always alter the rock movement geometry, and hence, the timing creates "effective" burden and spacing values that are often quite different from the burden and spacing that define the drill pattern. Timing will affect fragmentation, rock throw, and overbreak. Proper millisecond timing will enhance fragmentation and improve excavation productivity.

Delay blasting techniques can also be used to manage adverse geologic conditions and control of vibration and air blast effects. Major advantages of millisecond (MS) blasting are:

1. Reduction of ground vibration and air blast

2. Improved fragmentation
3. Reduction of overbreak and flyrock
4. Improved productivity and lower costs

Many easy-to-use non-electric systems that allow blasters almost infinite timing flexibility are offered by various manufacturers. A combination of surface and in-hole delays are widely used in construction blasting operations.
Another factor in blasting is rock-swell. This can vary from 20-40 percent of the bench volume. This can impact the blast performance if there is limited room. It can also affect the transportation requirements, which can impact both time and cost.

Vibration and Air Overpressure
When explosive charges detonate in rock, most of the energy is used in breaking and displacing the rock mass. However, some of the energy is released in the form of ground vibration and air overpressure or "airblast." Airblast pulses are usually in frequencies below the threshold of human hearing, but this energy can be felt. Human response to vibration and airblast is very subjective, and people can often feel very low levels of vibration and blast noise.

Ground Vibration
When explosives detonate in rock, energy is generated in the form of various surface and body vibration waves. Vibration wave energy decays with distance as it spreads through a rock mass or travels along the ground surface. Some waves pass through the "body" of the rock mass. These body waves are called primary (p) and shear (s) waves. Other waves—like Rayleigh and Love waves—travel along the ground surface. In an ideal isotropic and homogenous rock mass, wave energy would travel evenly in all directions. However, most rock masses are far from ideal, so wave energy is reflected, refracted, and differentially attenuated by various geological and topographical conditions. The elastic property of rock greatly influence vibration magnitude and attenuation rate.

Vibration Damage Control Criteria
The U.S. Bureau of Mines recommends the following:

1. Particle velocities of less than 51mm./s (2.0 in./s) show little probability of causing structural damage.
2. If there is at least 8 ms. (millisecond) separation between detonations, the vibration effects of individual explosions are not cumulative.
3. Particle velocity is still the best single ground motion description.
4. Damage potential for low-frequency blasts (< 40 Hz) is considerably higher than that for higher blasts (> 40 Hz).
5. Practical safe criteria for blasts that generate low frequency ground vibrations are 19 mm./s (0.75 in./s) for modern gypsum board partition houses and 12.7 mm./s (0.50 in./s) for lath and plaster interiors. For frequencies above 40 Hz, a safe particle velocity maximum of 51 mm./s (2.0 in./s) is recommended for all houses.
6. Human reactions to blasting can be the limiting factor. Vibration levels can be felt that are considerably lower than those required to produce damage.

Controlling Airblast

Excessive airblast is controlled by ensuring that all charges are properly confined. Excessive airblast is generated by the same poor confinement conditions that cause flyrock. Conditions that cause high over-pressure levels:

1. Inadequate stemming
2. Mud or weak seam venting
3. Inadequate burden confinement
4. Poor blasting timing
5. Focusing by wind or temperature inversions
6. Uncovered detonation cord
7. Overloading

Air blast from detonating chord trunklines can be significantly reduced if it is covered with at least 20 cm. (8 in.) of dirt or sand.

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