5

Explosives and blasting

“Unsafe acts and unsafe conditions cause accidents. Inculcating safe habits through training and education could bring accident rate near 0%.”

5.1 INTRODUCTION – EXPLOSIVES

An explosive is a substance or mixture of substances, which with the application of a suitable stimulus, such as shock, impact, heat, friction, ignition, spark etc., undergoes an instantaneous chemical transformation into enormous volume of gases having high temperature, heat energy and pressure. This, in turn, causes disturbance in the surroundings that may be solid, liquid, gas or their combination. The disturbance in the air causes air blast and this is heard as a loud bang. The disturbance in the solid structure results in its shattering and demolition. During wartime this property is utilized for destruction purposes but the same is used for dislodging, breaking or fragmentation of the rocks for quarrying, mining, tunneling, or excavation works in our day-to-day life. The energy released by an explosive does the following operations:

● Rock fragmentation
● Rock displacement
● Seismic vibrations
● Air blast (heard as loud bang).

5.2 DETONATION AND DEFLAGRATION

As stated above that when an explosive is initiated, it undergoes chemical decomposition. This decomposition is self-propagating exothermic reaction, which is known as an explosion. The gases of this explosion with an elevated temperature are compressed at a high pressure. This sudden rise in temperature and pressure from ambient conditions results into a shock or detonation waves traveling through the unreacted explosive charge. Thus, detonation (fig. 5.1(a)) is the process of propagation of the shock waves through an explosive charge. The velocity of detonation is in the range of 1500 to 9000 m/sec. well above the speed of sound. Deflagration (fig. 5.1(a)) is the process of burning with extremely rapid rate the explosive’s ingredients, but this rate or speed of burning, is well below the speed of sound.

5.3 COMMON INGREDIENTS OF EXPLOSIVES

Explosives are manufactured using fuels, oxidizers, sensitizers, energizers and few other substances in varying percentage. Given in table 5.1 is an account of type of ingredients usually used.
5.4 CLASSIFICATION OF EXPLOSIVES

Explosives have wide applications in mining and tunneling operations to carry out rock fragmentation for the differing conditions; hence, a wide range of this product is available. Given below is the general classification of explosives. Line diagram shown in figure 5.1(b) depicts this aspect.

5.4.1 PRIMARY OR INITIATING EXPLOSIVES

Primary explosives may be defined as those explosive substances, which respond to stimuli like shock, impact, friction, flame etc. and pass from the state of Deflagration (a high rate of burning) to detonation. Example: Mercury fulminates, Lead styphanate, Di-Azo-Nitrophenol (DDNP), Tetrazene etc. It is used in the manufacturing of the detonators, detonating fuses and boosters. The mixture of lead styphanate, lead oxide and aluminum powder, known as A.S.A mixture, is also used as a primary explosive.

5.4.2 SECONDARY EXPLOSIVES

These are the explosive substances, which are capable of detonation, created by a primary explosive and not by the deflagration. Thus these explosives have a high rate of detonation and initiated by the primary explosives. Example: Penta Erythritol Tetra Nitrate (PETN), RDX, Tetryl etc. These explosives are used in the manufacturing of the detonators and form their base charge.

Table 5.1 Common ingredients of explosives.\textsuperscript{7,11}

<table>
<thead>
<tr>
<th>Items</th>
<th>Ingredients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explosive itself</td>
<td>Fuels + Oxidizers + Sensitizers + Energizers + Miscellaneous Agents</td>
</tr>
<tr>
<td>Common fuels</td>
<td>Fuel oil, carbon, aluminum, TNT</td>
</tr>
<tr>
<td>Common oxidizers</td>
<td>AN, Sodium nitrate, Calcium carbonate etc.</td>
</tr>
<tr>
<td>Common sensitizers</td>
<td>NG, TNT, Nitro-starch, aluminium etc.</td>
</tr>
<tr>
<td>Common energizers</td>
<td>Metallic powders</td>
</tr>
<tr>
<td>Common miscellaneous</td>
<td>Water, thickeners, gelatinizers, emulsifiers, stabilizers, flame retarders etc.</td>
</tr>
<tr>
<td>Main elements of these ingredients</td>
<td>Oxygen, Nitrogen, Hydrogen and Carbon, plus, certain metallic elements such as: aluminum, magnesium, sodium, calcium etc.</td>
</tr>
</tbody>
</table>

Figure 5.1 (a) Conceptual diagrams – Detonation and deflagration phenomenon.
5.4.3 PYROTECHNIC EXPLOSIVES

Pyrotechnic compositions are used as a delay element in the manufacturing of the detonators and also as electric explosive devices (E.E.D), known as fuse-head or 'matchhead' or Squibb. Pyrophoric metals like zirconium or cerium, oxidizing agents like lead per oxide, red lead, chlorate of potassium, peroxides of barium and lead, and fuels like silicon, charcoal are used in delay element and EEDs.

5.4.4 LOW EXPLOSIVES

The earliest known explosives belong to this class. These are commercially known as gunpowder or black powder. It is a mechanical mixture of ingredients such as charcoal (15%), sulfur (10%) and potassium nitrate, \( KNO_3 \), (75%). It is initiated by ignition (deflagration) and decomposition is slow. Its flame propagates slowly; few m/sec. and burning particles are liable to remain in contact with the surrounding atmosphere for a considerable duration. It produces considerable amount of noxious gases rendering its use unsuitable for underground mines. It has heaving effect on the rocks and gets spoiled by water.

5.4.5 COMMERCIAL EXPLOSIVES – HIGH EXPLOSIVES

These are the explosive substances, which cannot be initiated easily by the stimulus such as impact, friction or flame but with the application of a shock pressure or a detonation wave. Example: Tri-Nitro-Toluene (TNT), Nitroglycerin (NG) and slurry explosives.
The various NG based explosives and their properties have been presented in table 5.2. These explosives can be classified as commercial and military explosives.

5.4.5.1 Gelatin explosives

 Nitroglycerin: It is produced by the reaction of glycerin and nitric acid. It is an oily fluid. It is so sensitive that by shock of any nature it can explode. To make it suitable for its industrial use either it must be absorbed in an inert material or it must be gelatinized. Explosive containing NG, are available three consistencies: Gelatinous, semi-gelatinous and powdery. Higher NG contents renders explosives gelatinous; lower NG content up to 10% powdery. NG based explosives (fig. 5.3(b)) can be divided into three classes:

- Dynamites (straight dynamite, ammoniac dynamite)
- Blasting gelatin
- Semi gelatin.

5.4.5.1.1 Dynamites (straight dynamite, ammoniac dynamite)

The NG based explosives were called dynamites. The first commercial explosive in NG was absorbed in natural mineral kieselghur, was termed as ‘Straight Dynamite’.

Later on ammonium nitrate was introduced and a mixture of AN, NG, NaNO₃, and fuel element was marketed as Ammonia Dynamite (fig. 5.3(b)).

5.4.5.1.2 Blasting gelatin

This is the most powerful explosive containing 92% NG and 8% Nitrocellulose (NC) which contains 12.2% nitrogen. Chalk, zinc oxide, air bubbles, acetone etc. are added to make the composition suitable for blasting purposes.

5.4.5.1.3 Semi gelatin

These are also termed as low NG, or high AN explosives due to the fact that in these explosives NG is mixed with NC, to form gel matrix which is mixed with AN in various proportions. Starch and wood meal are used as fuels. Straight gelatin and permitted explosive that are used in coalmines also fall in this category.

5.4.5.2 Wet blasting agents

Blasting agent is a mixture of fuel and oxidizer. It is not classified as an explosive, and cannot be detonated by a detonator (no. 8). A Dry Blasting Agent is a granular, free
running mix of solid oxidizer (usually AN); prilled into porous pellets, into which a liquid fuel or propellant is absorbed. The typical example is ANFO. Main ingredients required to produce wet blasting agents have been shown in table 5.3. The main ingredients to produce slurries and emulsion explosives have been also shown in this diagram.

The blasting agents that contain more than 5% water by weight are referred as wet blasting agents; within this category falls slurry explosives, water gels, emulsions, and heavy ANFO.

5.4.5.2.1 Slurry explosives
Slurry explosive is defined as a semi-solid or pasty suspension of oxidizers, fuel, sensitizers etc. in a thickener like guar gum. Inorganic cross-linking agents are added to prevent the segregation of solid and liquid on storage. The final product is the cross-linked water gel. The oxidizers commonly used are nitrates and perchlorates of ammonium, sodium and calcium. The fuels are glycol, starch, sugar, coal powder, sulfur etc. TNT, Nitro starch, finally divided aluminum powder; air bubbles are used as sensitizers. Micro-balloons of 3–4 microns size are also used as sensitizers. Slurry explosives are replacing the gelatin explosives due to the following characteristics they possess:

- Built in safety against fire, friction and impact
- Water compatibility
- Reductions in the production of toxic gases like CO and NO (fumes).

5.4.5.2.2 Emulsions
Emulsions are a two-liquid phase containing microscopic droplets of aqueous nitrates of salts (chiefly AN) dispersed in fuel oil, wax or paraffin using emulsifying agent. Micro-spheres, microscopic glass or plastic air filled bubbles, and AN droplet form the oxidizer. It is mostly mixed at site prior to charging into holes. It is also available in cartridge packs.

5.4.5.2.3 Heavy ANFO
Heavy ANFO is 45 to 50% AN emulsion mixed with prilled ANFO. This is done to increase density of ANFO. It is mostly mixed at site prior to charging into holes; but it is also available in cartridge packs.

Table 5.3 Composition of some slurries and emulsion (wet blasting agents).

<table>
<thead>
<tr>
<th>Slurry Explosives</th>
<th>Water Gel Explosive</th>
<th>Explosives sensitized slurry</th>
<th>Emulsion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al – 10%</td>
<td>Amine nitrate – 13%</td>
<td>TNT or Nitrostrach – 25%</td>
<td>Wax or Oil – 6%</td>
</tr>
<tr>
<td>Water – 15%</td>
<td>Water – 15%</td>
<td>Water – 25%</td>
<td>Water – 14%</td>
</tr>
<tr>
<td>NH₄NO₃ – 44%</td>
<td>NH₄NO₃ – 63%</td>
<td>NH₄NO₃ – 44%</td>
<td>NH₄NO₃ – 76%</td>
</tr>
<tr>
<td>Guar gum – 1%</td>
<td>Guar gum – 1%</td>
<td>Guar gum – 1%</td>
<td>Emulsifier – 2%</td>
</tr>
<tr>
<td>Ca(NO₃)₂ – 25%</td>
<td>NaNO₃ – 5%</td>
<td>NaNO₃ – 15%</td>
<td>Hollow micro-balloons – 2%</td>
</tr>
<tr>
<td>Ethylene glycol – 5%</td>
<td>Ammonium perchlorate – 3%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.4.5.3 Dry blasting agents

Powder explosives: One of the major applications of the prilled ammonium nitrate coated with an anti-caking agent is in the manufacture of powder explosives. These are used as powder or in the form of cartridges. Caking, bad fumes, poor water compatibility and low density are some its drawbacks. Its low cost, ease in manufacturing, handling and use has made it widely acceptable in surface as well as non-coal u/g mines. Detailed description is given in the following paragraphs.

5.4.5.3.1 Explosive ANFO

Ammonium nitrate: Ammonium nitrate (AN) is well known for its military and civilian use. It has been used extensively in both world wars to manufacture Amatol which is 80% + 20%, or 50% + 50% mixture of AN and TNT. It is an excellent fertilizer. Explosive properties of AN was known accidentally when a shipload of fertilizer grade AN blew up suddenly due to a fire accident. It was considered a potential blasting agent since then.

Ammonium nitrate, which was earlier known as an oxidizer in the manufacturing of explosives, has become the principal ingredient of the commercial explosives in use, in the mining industry. Today due to some of its inherent properties AN based explosives are in use all over the world. In the commercial explosives AN percentage varies in the range of 10–95%. In all the principal classes of explosives i.e. NG based, dry and wet blasting agents AN is used. When AN is mixed with 5–6% fuel oil, the mixture is known as ANFO. ANFO has become an indispensable explosive for most of the surface mines and underground non-coal mines.

5.4.5.3.2 ANFO mixing

Most porous prilled AN absorbs oil up to 6–7%. Excess oil collects at the bottom of the container. Since 6% is approximately the stoichiometric value of oil, preparation of this blasting agent is comparatively simple. Accurate compounding and thorough homogeneous mixing is all that is required to give a superior product.

Earlier practice which is still followed is to pour AN in the dry holes and then pour fuel oil in it. In large dia. holes with large primer this gives moderately satisfactory results. This practice is now replaced by surface mixing. Care should be taken to put correct amount and give sufficient soaking time. Most satisfactory method, however, is to provide some type of mechanical mixer with careful control of quantities. A uniform product can be obtained by mixing in any of the conventional mixers. A mixer should minimize frictional heating and crushing of prilled material. From safety consideration, a mixer should provide minimum confinement.

Addition of a oil soluble dye “waxoline red” of 1 gm. per liter gives slight pink coloration to the mixed product and also helps to achieve a uniform mixing denoted by color index. Too much of the dye mars the judgment of uniform mixing. It has been found that with oil of 0.82 S.G. 100 kg of AN needs 7.6 liters; to give a mixture of 6% by weight. It is again stressed that smaller the diameter of hole, the care while mixing should be more to get better results. It has been recommended that under extreme cold climate a little preheating of oil at least 20°C below the flash point gives better mixing because of increased inter molecular activity.

5.4.5.3.3 ANFO loading

ANFO loading in large diameter down holes is hardly any problem because the mixed ANFO can be directly poured inside the holes. For large diameters, mixed
ANFO, is also available in a cartridge form, which can be loaded like any other explosive. Only for small diameter holes, loading has to be done by pneumatic means for quick, compact and thorough loading. The loading equipment is known as Anoloaders. The loaders are broadly of two types:

1. Pressure type (fig. 5.2(b))
2. Ejector type, who’s principal of working is important to note at this stage (fig. 5.2(a))
3. Combine type (combining pressure and ejecting features).

5.4.5.4 Pneumatic loaders and principles of loading

5.4.5.4.1 Pressure type loaders
These are heavy duty and fast loading transportable machines and can load effectively up to 25 meters of vertically up holes. In this particular type unlike the other ejector type a plug of ANFO mixture is forced to reach the hole against a positive pressure as a continuous column, whereas in the ejector type the ANFO particles are blown along with a continuous current of air. In the ejector type, the ANFO particles bombard against the loaded front and gets broken, resulting into compaction, but in the pressure type the prills crack against the positive pressure from one side and as soon as ANFO
leaves the loading hose, it is broken into smaller fragments. The pressure type loader (fig. 5.2(b)) essentially consists of: a tank with cap, discharge valve, air cylinder and remote control unit, and gauges.

In pressure type loaders, the loading rate is directly dependent upon the pressure suitable for loading. An increased pressure develops in blowing of ANFO out very fast, whereas, a decrease in pressure results in locking of ANFO inside the loading hose. It is a matter of experience as it is to be decided based on the parameters such as: length of hole and its direction, condition of the mixed ANFO whether it is moist or dry, prill sizes’ uniformity, and whether ANFO is powdery or not.

5.4.5.4.2 Ejector type loader
This is a portable air operated loader (fig. 5.2(a)) for ANFO loading in holes of small length and diameters. It loads with a high density and with high speed when operated properly. This model has no ‘blocking problem’ as in case of pressure type where because of pressure from one side and resistance from other side ANFO gets blocked sometimes in the loading hose. This type has a specially designed ejector, hence the name.

Assembly: It has anti-static loading hose 20 to 25 mm diameter and 3 to 4 m long with a protective spring to prevent excessive flexing of the hose. A clamp tightens hose with the diffuser ejector. It has a compressed air inlet of 25 cm. It has also a permanent grounding lug on the ejector body for earth connection. A self-adhesive color tape is fixed on the discharge end of loading hose to note the length of hose inserted in the hole.

Operation: Safety glasses and gloves must be worn while working with the loader. Operator should be on one side of the hole and never to the front directly. It operates on direct air pressure and on the squeeze of hand operated valve. No air lubricator should be used with an loader air supply.

5.4.5.4.3 Combine type (combining pressure and ejecting features)
By combining the application of both the mechanisms, the loader (5.1(a) and (b)) can achieve double the rate of loading than that in pressure type and cope up with hole length up to 30 m effectively.

5.4.5.5 Safety aspects

● Safety record of ANFO explosives is excellent as compared to conventional explosives. But it cannot be said that accidents cannot and will not occur. ANFO mixture is non-cap-sensitive. This mixture is also insensitive to friction and impact tests as generally applied to high explosives. However, a strong booster is used so that satisfactory initiation is resulted. This in itself does not create any hazard if the transport, loading and firing is conducted in the same manner as recommended for other explosives. Their propagation through an air gap is poor. Air pocket up to 25 to 50 mm may result in failure of blast. Cap-sensitive ANFO has also been developed by repeated temperature cycling through the 90°-phase change region. Evidently these mixtures can be treated as cap-sensitive high explosives. But unfortunately these cap-sensitive explosives are very costly.

● Danger of fire is perhaps the greatest hazard with ANFO, although small quantities of ANFO are difficult to burn. For safety aspects, ANFO is recommended to be used in the same manner as other high explosives.

● ANFO has a tendency of spontaneous heating in pyrite bearing ores. ANFO has been found to react with pyretic ores at as low as 85°C resulting in an exothermic
reaction. Addition of 0.5 to 1% of calcium carbonate, urea, zinc oxide or magnesium oxide decreases the reactivity. However, the percentage of pyrites in the ore that affects this phenomenon is 5 to 30% by weight. Use of ANFO in pyritic ore bodies should be done with care specially in hot ground conditions. Exothermic reaction can produce temperature exceeding thermal initiation of charge.

- During handling AN has a corrosive action on human skin resulting into black patches and scaling of skin. So a rubber glove is recommended for ordinary use. AN dissolves on the skin moisture and goes in subcutaneous area causing irritation.
- Electrostatic hazards of pneumatic loading are very important and are dealt with in the following paragraph.

5.4.5.6 Static hazards associated with anfo loading

Static charge is built up on the loading hoses and equipment and the problem has been the greatest so far in the usage of ANFO underground.

Certain degree of safety can definitely be achieved by using conductive, or semi-conductive hose, and the established standards so far. The salient points may be summarized as follows:

a. The loading hose should be semi-conductive with a resistance high enough to insulate any stray current yet conductive enough to bleed off any static charge builds up. Such loading hoses are called ‘LO STAT’ and a yellow stripe runs through out their length to identify them.

b. The electrical characteristic of the loading hose should be uniform throughout its length. Resistance lying between 17,000 and 67,000 ohms/m; electrical capacity of typical PVC hose is 4 p.f. and available discharge energy is 24 MJ. Basically it should have sufficient resistance to corrosion from oil and stiff enough to avoid too much kinking.

c. Except in case of non-electric detonators like Anodets etc. bottom priming should not be done and priming should be done at the collar at the end of loading allowing sufficient time for the hole and operator to get discharged of any electric static charge.

d. The entire system and the operator should be effectively grounded with the earth. Only approved semi-conductive loading hose should be used. In case of hoses lined with a non-conductive material pneumatic loading should not be adopted.

e. Maximum resistance of the drill hole to the ground must be less than 10 Mega ohms and the maximum resistance of the loader operator to the ground must be less than 100 mega ohms, while electric detonators are to be used.

f. After every loading operation some time should be allowed for the charge to leak away and the detonator should be placed from the collar side, and the operator should also ground himself before handling to the detonators.

g. Detonator continuity test must be made religiously. This will prevent discharge between the shell and the lead wires, which may be of corona type, or a simple spark.

h. Leg wires should be shunted and not connected to ground during pneumatic loading.

i. Effective earth line should be connected with the entire assembly of ANFO loader.

j. Synthetic fibers like nylon, teryline etc. should not be on the body of the persons doing ANFO loading since they have tendency to accumulate and retain charge. For similar reasons rubber-soled boots should also not be used.

The quantity of electric charge has been seen to depend largely upon humidity conditions and general conductivity of the rocks. When the rock is fairly conductive, the charge is dissipated as soon as developed.
As discussed earlier ‘Anodet’ or antistatic detonators have obviated the use of electric detonators in the ANFO blasting system, as such use of the ordinary electric detonators should be avoided.

5.4.5.7 Special types of explosives

5.4.5.7.1 Permitted explosives

These explosives have been designed to use in u/g coalmines to avoid methane-coal dust explosion. These are available in granular, gelatinous and slurry forms. For wet coal mines gelatinous type is more suited. The V.O.D of these explosives is in the range of 6000 to 16,000 ft/sec. A cooling agent is incorporated in all permitted explosives. Common amongst them are sodium chloride, potassium chloride and Ammonium chloride.

A 3 mm thick cover (sheath) of sodium bicarbonate, when wrapped all along the length of the cartridge, this is known as Sheathed explosive. This is also a permitted type of the explosive, which can be used in coalmines.

5.4.5.7.2 Seismic explosives

In seismic exploration work for mineral discovery, shots are fired in the earth crust, often under the high heads of water, so that the resulting ground vibration reading can be recorded by the geophones in some selected areas. The trade name given varies from company to company e.g. Seismograph high explosive, Petrogel, Geogel etc.

5.4.5.7.3 Overbreak control explosives

For smooth, perimeter blasting (sec. 9.3.3) special types of explosives often of giving a poor coupling ratio, having the diameter of cartridge in the range of 5/8–7/8” are used. The trade name given varies from company to company e.g. ‘Smoothite’, ‘Kleen-cut’ etc.

5.4.6 MILITARY EXPLOSIVES

These explosives are less sensitive to impact and shock compared to dynamites. They show high brisance or shattering effect. Brisance is described as the ability of explosive to shatter and fragment steel, concrete and other very hard structures. Their velocity of detonation is in the range of 7000 to 9000 m/sec, comparing the same for the commercial explosives, which is up to 5000 m/sec. These are known by the names such as: TNT, PETN, RDX, TETRYL etc. They have high detonation pressures of the order of 17 million p.s.i. The components are either melted or pored or casted into shells or suspended. These explosives features following characteristics:

- Maximum power/unit volume
- Minimum weight/unit power
- High velocity of detonation
- Long term stability under adverse storage conditions
- Insensitivity to shock on firing and impact.

Common properties of military explosives have been shown in Table 5.4.

Other military explosives include the mixtures such as Ammonium salt of picric acid (Picramate), Dinitro toluene (DNT), ethylene diamine dinitrate (EDDN), Ammonium nitrate (AN), cyclotol (RDX + TNT), composition ‘B’ (RDX + TNT + Wax),

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Torpex (RDX/H11001/TNT), Ametol (TNT/H11001/AN), Pentolite (PETN/TNT), Tetrytol (Tetryl/TNT) and many more compositions. NG is normally used in making ‘double based’ propellants.

5.5 BLASTING PROPERTIES OF EXPLOSIVES

Each explosive has certain specific properties or the characteristics. Its ingredients such as nitroglycerin and ammonium nitrate contents have direct influence on some of its properties such as resistance to water, detonation velocity, costs etc. These aspects were studied, as shown in figure 5.3. Given below are some of the important properties, which influence the ultimate choice of an explosive.

5.5.1 STRENGTH

It is the energy released/unit weight (known as weight strength); or per unit volume (known as bulk strength) of an explosive. It is now a days expressed relative to ANFO at 100% i.e. taking ANFO as standard. High strength is needed to shatter the hard rocks but use of high strength explosive in the soft; weak and fractured rocks will be wastage of the excessive energy imparted by these explosives. Strength of an explosive is measured by:

- Shock generated (VOD and speed of chemical reaction)
- Gas volume
- Energy
- Detonation pressure
- Explosion temperature
- Shock generated (VOD and speed of chemical reaction)

<table>
<thead>
<tr>
<th>Explosive</th>
<th>Density gms.c.c</th>
<th>VOD m/sec</th>
<th>Gas vol lit/kg</th>
<th>Detonation kcal/kg</th>
<th>Temp °C</th>
<th>Sp. pressure kg/cm²</th>
<th>Lead block expansion mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trinitro toluene – TNT</td>
<td>1.63</td>
<td>6950</td>
<td>685</td>
<td>1085</td>
<td>3630</td>
<td>3749</td>
<td>310</td>
</tr>
<tr>
<td>Penta erythritol tetramotrate – PETN</td>
<td>1.77</td>
<td>8300</td>
<td>780</td>
<td>1408</td>
<td>3560</td>
<td>–</td>
<td>500</td>
</tr>
<tr>
<td>Cyclo trimethylene trinitremine – RDX</td>
<td>1.73</td>
<td>8500</td>
<td>910</td>
<td>1390</td>
<td>3380</td>
<td>4150</td>
<td>485</td>
</tr>
<tr>
<td>Trinitro phenyl methyl nitromine – TETRYL</td>
<td>1.06</td>
<td>7500</td>
<td>710</td>
<td>1320</td>
<td>3370</td>
<td>4684</td>
<td>450</td>
</tr>
<tr>
<td>Nitroglycerin – NG</td>
<td>715</td>
<td>1470</td>
<td>3153</td>
<td>4060</td>
<td>390</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HBX (RDX + TNT + Wax)</td>
<td>782</td>
<td>1435</td>
<td>3500</td>
<td>–</td>
<td>480</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Velocity of detonation (VOD) is the measure of the shattering effect of an explosive, an important parameter for hard rock blasting. It changes with change in diameter and density of explosives. 'Dautriche', electronic or Hess method or tests can measure VOD.

- **Gas volume**
  Larger the gas volume of an explosive large will be the throw obtained. If throw is to be minimized its ingredients should be adjusted to get minimum volume of gas and maximum heat output. ‘Ballistic Mortar’ test and ‘Trauzl block’ test generally measure it.

- **Energy**
  The oxygen balance and reactive ingredients determines the energy output of an explosive. This energy represents the temperature of explosion and hence the maximum work that can be done by an explosive is indicated by this value.

- **Detonation Pressure**
  Based on detonation velocity and density of explosives a shock wave pressure that is built ahead of reaction zone is known as detonation pressure. Higher the detonation pressure, higher would be the brisance capability (i.e. the ability to break or shatter rock by shock or impact). Its value varies from 5 to 150 KB. Due to this property a primer having higher detonation pressure should be selected. Given below is the mathematical relation to express this parameter:

  \[
  p = 2.5 \rho v^2 \times 10^6 
  \]  
  (5.1)

  Where as:  
  - \( p \) = detonation pressure in kilobars (KB)  
  - \( \rho \) = explosive density in gms/c.c  
  - \( v \) = velocity of detonation in m/sec.

  Above the critical density, detonation pressure is zero, as the cartridge does not explode.

- **Explosion temperature**
  This parameter is calculated based on the thermodynamic data of the ingredients. In coal mines a balancing of explosion temperature and the gas volume play an important role. If explosion temperature exceeds 1000°C it can make the methane atmosphere incendive i.e. mixture of air & methane can catch fire and explode.

### 5.5.2 DETONATION VELOCITY

It is the velocity with which the detonation waves move through a column of explosives. Following are the factors that affect the detonation velocity:

- Explosive type,  
- Diameter, Confinement,  
- Temperature &  
- Priming.

In general, higher the velocity of detonation better will be the shattering effect. The explosive’s detonation velocity ranges from 1500–6700 m/sec.

In general, larger the diameter the higher is the velocity of detonation until a steady state velocity is reached. For every explosive there is a minimum critical diameter at which the detonation process once initiated, will support itself in the column. The influence of hole dia. on the detonation velocity for various types of explosives has been studied, as shown in figure 5.3(a).
(a) Variation in detonation velocity with borehole diameter for few selected explosives as per the blast-hole diameters. (Conv. 1" = 25.4 mm; 1 fps = 0.3048 m/s)

(b) Relation of ingredients and properties of explosives

(c) Influence of oil content in ANFO contributing to toxic gases productions

Figure 5.3  Explosives’ characteristics.
5.5.3 DENSITY

The explosives’ density is in the range of 0.5 to 1.7. A dense explosive release more energy/unit volume, hence it is useful for the hard and denser strata. For any explosive there is a critical density, above which, it cannot reliably detonate. For example for TNT – 1.78 gms/c.c; ANFO – above 1 gms/c.c.

5.5.4 WATER RESISTANT

A practical way to judge the ability of any explosive to resist water is its capability to withstand exposure to water without losing sensitivity or efficiency. ANFO is poor water-resistant. Slurries are good water-resistant, and whereas, the NG based explosives are the best water resistant, as shown in figure 5.3(b).11

5.5.5 FUME CHARACTERISTICS, OR CLASS, OR MEDICAL ASPECTS

An explosive after blasting should generate minimum amount of toxic gases such as carbon mono oxide, oxides of nitrogen etc. It varies from 0.023 m³/kg (fume volume/unit weight) to as high as 0.094 m³/kg. In some of the NG based explosives, the fumes emitting out from it, enters into the blood circulation-causing headache.

5.5.6 OXYGEN BALANCE7,8

As stated above that any explosive contains oxidizing and combustible (fuels) ingredients. A proper balance of these ingredients is essential to minimize production of the toxic (poisonous) gases, e.g. an excess of oxygen produces such as nitric oxides, nitrogen peroxide and deficiency of oxygen result in the production of carbon monoxide. Also such an imbalance effects the energy generation. This can be illustrated by taking example of ANFO explosive, which is mixture of ammonium nitrate and fuel oil. The former acts as an oxidizer and the later a combustible agent. While mixing them in varying percentage, the resultant reactions can be represented by the chemical reactions as under:

\[
3NH_4NO_3 + CH_2 \rightarrow 7H_2O + CO_2 + 3N_2 \quad + 0.93 \text{ Kcal/gm. oxygen balanced}
\]

\[
2NH_4NO_3 + CH_2 \rightarrow 5H_2O + CO + 2N_2 \quad + 0.81 \text{ Kcal/gm. oxygen balance - negative, fuel in excess.}
\]

\[
5NH_4NO_3 + CH_2 \rightarrow 11H_2O + CO + 4N_2 + 2NO \quad + 0.60 \text{ Kcal/gm. oxygen balance - positive, oxidizer in excess.}
\]

The above equations and figure 5.3(c),13 illustrates that an oxygen balanced mixture generate minimum harmful gases and maximum energy.
Calculation of oxygen balance: Oxygen balance can be determined by following the steps outlined below:

- Write the molecular formula and molecular weight.
- Find number of C, O, H and nitrogen atoms.
- Remove two oxygen atoms/carbon atom (CO₂); and half oxygen per hydrogen atom (H₂O formation).
- Leave nitrogen atom as nitrogen molecule (N₂).
- Note, how much oxygen is left behind (+). If not then calculate how much oxygen is required (−).

\[ C_aH_bN_cO_d = aCO_2 + 0.5bH_2O + 0.5cN_2 + (d - 0.5b - 2a)O_2 \] (5.3)

Where as a, b, c, and d are the number of carbon, hydrogen, nitrogen and oxygen atoms in the explosive substance.

Example: To calculate oxygen balance of the fuel oil.
Formula: CH₂  Molecular weight = 12 + 2 = 14

\[ a = 1, b = 2, c = 0, d = 0 \]

\[ (0 - 0.5 \times 2 - 2 \times 1) = -3 \text{ atoms of oxygen.} \]

14 gms of diesel oil require 48 gms of oxygen, so 1 gm of diesel oil will require \( \frac{48}{14} = 3.43 \). So, oxygen balance of fuel oil is 3.43.

Similarly calculation of oxygen balance of ammonium nitrate (NH₄NO₃).
Molecular weight = (14 + 4 + 14 + 48) = 80

\[ a = 0, b = 4, c = 2, d = 3 \]

Oxygen balance = \( (d - 0.5b - 2a)O_2 = (3 - 0.5 \times 4 - 2 \times 0) = 1 \text{ atom of oxygen} \)
80 gms of ammonium nitrate gives 16 gms of oxygen, So 1 gm of ammonium nitrate will give = \( \frac{16}{80} = 0.2 \text{ gms of oxygen.} \)

For ANFO to be oxygen balanced:
AN \times 0.2 + \text{fuel oil} \times (-3.4) = 0

Let, AN be y%  
0.2y + (100 - y)(-3.4) = 0

Or 3.6y = 340; or y = 94.5

Thus, an oxygen balancing ANFO should contain 5.5% fuel oil and 94.5% ammonium nitrate.

Calculation of oxygen balance of Nitroglycerin:
Molecular formula: C₅H₈N₄O₁₂
Molecular weight = (12 \times 3 + 1 \times 5 + 14 \times 3 + 16 \times 9) = 227

Oxygen required or available = \( (d - 0.5b - 2a) = (9 - 0.5 \times 5 - 2 \times 3) \)
= 0.5 atoms of oxygen

So oxygen balance = Molecular weight of available oxygen/molecular weight of substance = \( \frac{0.5 \times 16}{227} = 0.035 \)

Calculation of Oxygen balance of PETN

Formula: C₅H₈N₄O₁₂  Molecular weight = 316
Oxygen required = \( (d - 0.5b - 2a) = (12 - 0.5 \times 8 - 2 \times 5) \)
= -2 atoms of oxygen = -32 gms.
Oxygen balance = -32/316 = -0.1
5.5.7 COMPLETION OF REACTION

Achieving a complete reaction at the required speed during blasting is the next important factor, for example if a carbon atom is not oxidized to carbon dioxide but carbon monoxide, the production of energy comes down by 75% of the expected energy, as shown below. Similarly, formation of oxides of nitrogen involves the absorption of energy.

\[
C + O_2 \rightarrow CO_2 + 94 \text{ Kcal/gm.} \quad (5.4a)
\]

\[
0.5N_2 + 0.5O_2 \rightarrow NO - 22 \text{ Kcal/gm.} \quad (5.4b)
\]

\[
C + 0.5O_2 \rightarrow CO + 26 \text{ Kcal/gm.} \quad (5.4c)
\]

Reaction (eq. 5.4(b)) and (eq. 5.4(c)) not only produces lower energy but also yield toxic gases. In ANFO explosive if moisture content exceeds 1%, it not only causes caking of ANFO but also makes the reaction incomplete.

5.5.8 DETONATION PRESSURE

Based on detonation velocity and density of explosives a shock wave pressure, which is built ahead of reaction zone, is known as detonation pressure. Higher the detonation pressure higher would be the brisance capability. Its value varies from 5 to 150 KB. Due to this property a primer having higher detonation pressure should be selected. Using equation (5.1) detonation pressure can be assessed.

5.5.9 BOREHOLE PRESSURE AND CRITICAL DIAMETER

It is an important parameter, which measures the breaking and displacement property of an explosive. Its value varies from 10–60 KB (1000 to 6000 kpa).

Critical diameter: Sensitivity of an explosive is an important property, which is measured by its ability to propagate the detonation wave. The detonation wave tends to fall or fade when diameter of explosive charge decreases. The minimum diameter of a charge, below which the detonation does not proceed, resulting in misfire, is called ‘Critical Diameter’. At lower diameter even if the explosive is sensitive, the reaction in the cartridge may be incomplete.

5.5.10 SENSITIVITY

It is measured as the explosive’s propagation property to bridge a gap between two consecutive cartridges or a column of an explosive charge e.g. if a cartridge is cut into two halves, and the resultant pieces are kept apart. By initiating one of them, with how much gap the other will be able to accept the propagation wave, if blasted unconfined in a paper tube.

5.5.11 SAFETY IN HANDLING & STORAGE QUALITIES

ANFO is having poor storage quality being hygroscopic in nature. ANFO if handled without gloves can cause skin irritation. Also salt of some explosives under extreme temperature conditions evaporates, making its cartridges hard and deformed. By proper waxing of the explosive cartridges the effect of moisture on them can be minimized.
One of the important requirements of an explosive is that it can be stored, transported and used under the normal conditions without any risk to the persons handling it and carrying out the blasting operations. In order to have a safe manufacturing, transport, handling and the end use of an explosive, various tests are made on the ingredients and final product. The tests include Impact test (fall hammer test), Friction pendulum test, Torpedo friction test, Projectile impact test and bullet sensitivity test. For example, NG powder will explode if a weight of 0.5 kg fall on it from a height of 20–30 cms. Whereas if a weight of 0.5 kg falls from about 8 m on it, a cap-sensitive slurry may explode.

### 5.5.12 EXPLOSIVE COST

While selecting an explosive its cost plays an important role. Comparing to AN (Ammonium Nitrate), the relative cost of some of the common explosives on unit weight basis has been given in table 5.5.

### 5.6 EXPLOSIVE INITIATING DEVICES/SYSTEMS

Any explosive needs stimuli like shocking, friction or flaming for it to blast, or the reaction to initiate in it. The devices used to carryout these operations are known as initiating devices. The description below outlines the development and application of each of such devices/techniques to initiate an explosive. In line diagram (fig. 5.4), classification of explosive initiating devices/systems has been shown.

#### 5.6.1 DETONATOR SYSTEM

##### 5.6.1.1 Detonators

In order to initiate high explosives and the blasting agents, a strong shock or detonation is required. A capsule of sensitive explosive material termed detonator can
accomplish this. A detonator consists of a metal tube or shell (Cu, bronze or Al), generally 5.5 to 7.5 mm in outer diameter and a varying length depending upon whether it is instantaneous or delay type (fig. 5.5).

In a detonator at its bottom a base charge PETN (Secondary explosive) is placed. To initiate this base charge a column of primary explosive, which is a mixture of lead styphnate, lead oxide and aluminum powder, known as A.S.A mixture is placed over it. The charges are compacted under adequate pressure to give the desired strength.

**Strength of a detonator**: Based on the quantity of base charge and A.S.A charge quantity; the detonators are designated as detonator no. 1 to no. 8, or more in the order of increasing quantities of these charges. Thus, No. 8 cap produces much stronger pressure pulse than no. 6 cap. No. 6 detonator contains 0.35 gms of A.S.A mixture and 0.25 gms of PETN or tetryl. No. 8 carries large charge, 25% more than No. 6, and used to blast hard rocks.

The method of initiating the charge may be a safety fuse, as in case of plain detonator or by a fuse head as in case of electric detonator.

5.6.1.2 Instantaneous detonators

5.6.1.2.1 Plain detonator

This is simpler in construction and made of an aluminum shell closed at bottom and open at the other end (fig. 5.5(a)). It is used under dry and non-gassy conditions and initiated by the safety fuse that is inserted in its open end and crimped.
5.6.1.2.2 Instantaneous electric detonators

These detonators (Fig. 5.5(b)) have the same construction as the plain detonators except that an electric explosive device, often called fuse-head, is used to initiate primary explosive charge incorporated within it. In this detonator a bridge wire is provided, and the mouth of the tube is sealed with a plastic plug through which the insulated leg wires pass. Proper electric current, when passed through the bridge wire of the fuse head, it fuses it; thereby it becomes incandescent and ignites the priming charge. The detonator is fired instantaneously i.e. at the same time, as the current is passed.
5.6.1.3 Delay detonators

5.6.1.3.1 Electric delay detonators
These are manufactured as two varieties – Long/half second delay detonators and short/millisecond delay detonators. These detonators (fig. 5.5(c)) are longer in length than the instantaneous electric detonators as a delay element is incorporated between the primary charge and the fuse head. Long delay detonators are available in 0–15 numbers, with a nominal half-second time interval between each delay.

In short delays the delay interval is much shorter. These types of detonators are available in a wide range of intervals using no. 6 and no. 8 strength caps. These short delays can be further classified as normal and non-incendive delays. The normal detonators are available in the range of 18–38 delays each interval varying from 8 to 100 or more milliseconds. The leg wires’ length is in the range of 4 to 60 ft. These delays are widely used in mines other than u/g coalmines. They are also used in tunnels.

The non-incendive types of detonators are used in coalmines and are made of copper tubes with copper leg wires of 4–16 ft lengths. These are available in 10 delays with interval of 25–75 milliseconds. Both types can be used in wet conditions.

5.6.1.3.2 Electronic delay detonators
An electronic delay detonator is very recent and in its exterior appearance it looks like a conventional detonator. The detonator is marked with delay period number from 1 to 250. This number does not indicate delay time but only the order in which the detonators will be fired. Each detonator has its own time reference, but the final delay time is determined through the interaction between the detonators and the computerized blasting machine before their firing.

Dyno Nobel is one of the companies who are manufacturing this. In this system detonators react to the dedicated blasting machine eliminating risk of unintentional initiation by any other energy source. In the manufacturing of this detonator several elements are used as the chain reaction of igniting the detonator, and detonating the charge in the drill hole. Each element involves a time delay, which is not the same for all normally equal detonators. The reason is that each element has a certain amount of delay time.

Figure 5.5 (h) Hercudet system with detonator.
scatter time. In figure 5.5(g) the internal structure of an electronic detonator has been shown. Apart from base charge (PETN) and primary explosives, lead wires and sealing plug like in the conventional detonators, the other important components include: match head with bridge wire, an integrated chip, capacitor and an over voltage protection circuit. Not detonating without a unique activation code and protection against excessive voltage are some of its unique features that allows it to be safer than the conventional detonators. The blasting machine is the central unit, which supplies detonator the initiation energy and allocates it the delay time. These are some of the specific features of these detonators:

- Shortest delay time is 1 ms and longest is 5.25 seconds.
- In this system maximum up to 500 detonators can be connected to the blasting machine.
- The filter combination with toroid, gives protection against parasite currents, static electricity produced during pneumatic charging of explosives or radio frequency signals.
- They are extremely precise to the extent of 0.2 ms.
- The limitation at present is their costs, which is 10–15 times the conventional caps.

5.6.1.3.3 Non-electric delay detonators: detonating relays (ms connectors)

This system is used in conjunction with detonating cords (DC) for blasting large number of holes and is capable of introducing millisecond intervals (delays) between holes or rows of holes. A detonating relay consists of a long aluminium tube with two mini-delay detonators on both side and having an attenuate in the center. The opening at either end can be crimped to detonating cord. These are manufactured with delay interval of 15, 17, 25, 35, 45, 50, 60 and 100 ms. Use of such relays can provide advantages such as easy and safer to handle, better fragmentation, reduced ground vibration, better muck pile and reduction in overall costs. Only one detonator is required to fire a blast. Their placement in wet conditions should be avoided. The system finds its applications in surface mines and u/g metalliferous mines.

5.6.1.3.4 Primadet and anodet non-electric delay blasting systems

To safeguard against the static charge and current hazards from the electric detonators Ensign Backford developed the primadet system. It consists of three components:

1. A blasting cap (no. 6) with delay elements (short or long delay). Short delay system with 30 delay periods ranging from 25 to 250 milliseconds.
2. A detonating cord having PETN of 4 grains/ft. called primaline. One end of which is crimped into the blasting cap at the time of its manufacturing. It is available in different lengths 2 m to 15 m (6–50 ft).
3. A plastic ‘J’ connector for readily attaching the free end of the primaline to the trunk line.

Anodet (figs 5.5(e) and 5.9(e)) is similar to primadet and it has been developed by CIL for its use during charging ANFO pneumatically in the blastholes of 25 to 70 mm. The primaline is known as Anoline in this system. In this system to locate the primer centrally in the hole the manufacturer also supplies a plastic cap holder. The Anoline is available in the length of 3, 4, or 5 m. Anodet short delays are available from 0–30 numbers. Long delay are available from 0–15. In figure 5.9(e) procedure to use an anodet detonator together with its accessories has been illustrated.
5.6.1.3.5  **The Nonel system**\(^{10,13,14}\)

It is an invention by Nitro Nobel AB Sweden used as a nonelectric system without use of detonating cords (fig. 5.5(f)). The manufacturer as a standard pack of the following four components supplies it:

1. a Nonel tube – it is a transparent tube having 3 mm external dia. with 1.5 mm. bore. Inside wall of this tube is coated with low concentration of explosive powder that posses the ability to conduct a shock wave at constant velocity.
2. a plain detonator with a delay element.
3. a connecting block, provided with a mini-detonator – which supplies the shock wave to the Nonel tube.
4. a starting gun and Nonel trunk line.

A special gun initiates the complete circuit that energies a Nonel trunk line, which in turn initiates each connecting block connected to it. The mini-detonator in the connecting block supplies the shock wave. It travels through the tube and emerges in the detonator as intensive tongue of flame. The Nonel detonators are supplied in the range of 20 delay intervals each of 25 milliseconds, and six more each of 100–150 milliseconds.

Nonel is a closed system. Each hole is supplied with a separate Nonel unit and a simple manual operation connects each unit to the preceding one. The ignition impulse, once ignited, is transmitted from unit to unit via the connecting blocks. Several rounds may be fired in parallel. Since the system is non-electric, no balancing or instrument checking is required.

The system virtually eliminates accidents common with electrical blasting system while at the same time radically simplifies the blasting operations.

5.6.1.3.6  **Combine primadet-nonel system**

Now a days combine system for a variety of precise non-electric hook ups (LP & MS) for underground applications is available. The primadets are connected with a Nonel shock tube instead of primaline.

5.6.1.3.7  **The Hercudet blasting cap system**\(^{14}\)

This system also eliminated all the hazards associated with the use of electric detonators. It is practically noiseless. It consists of the following three major elements (fig. 5.5(h)):

1. A special aluminium shell Hercudet detonator, having a delay element and two plastic tubes in place of two legs wires (as in an electric detonator) (fig. 5.5(h)).
2. Hercudet connectors for connecting lengths of tubing between adjacent holes in the circuit.
3. Hercudet blasting machine (with bottle and tester).

In Hercudet system the detonators are connected in the circuit as shown in figure 5.5(h). To fire the round, the valves on the bottle box are opened to charge the blasting machine with the firing mixture of fuel and oxidizer, the ‘arm’ button is pressed for a short time, and then the ‘fire’ button. This initiates the gas mixture in the ignition chamber of the blasting machine, resulting in a detonation that proceeds at about 300 m/sec (1000 ft/sec) and initiate all the detonators. Hercudet system has been developed in USA. This non-electric system does not require any detonating cord, as the other non-electric systems such as primadet, anodet etc. need. This factor obviates excessive noise resulting from most other non-electric systems.
The system consists of a delay blasting caps appearing like the conventional ones, but with hollow plastic tubes replacing wires or detonating cord. Tubes have no explosives or other filling or coatings. In use the caps are connected together via a tube circuit and when all connections are made, the hook up is checked for continuity. After thus proven, a mixture of fuel oxidizer gases is introduced to fill tubing. A spark produced in the ignition chamber within the blasting console then causes reaction to travel at a speed of 200 m/sec. throughout the circuit activating all the caps.

5.6.1.3.8 Advantages of short delay blasting
Advantages of the blasting with the use of short delay millisecond detonators comparing the same with half second or instantaneous delays are as under:

- Reduction in ground vibrations
- Reduction in air concussion
- Reductions in over-break
- Improved fragmentation
- Better control on fly rock.

5.6.2 Fuse/Cord System

5.6.2.1 Safety fuse
William Blackford in 1883 introduced safety fuse to initiate gun powder/black powders. Safety fuse consists of a core of fine-grained gun powder/black powder, wrapped with layer of tapes or textile yarns and waterproofs coating, to guard against moisture and shock. Its rate of burning is 600 mm/min. It is available in a coil of 915 m (3000 ft).

5.6.2.2 Detonating fuse/cord (DC)
Detonating fuse is a cord having a primary explosive, such as PETN, as its core and warping of textile fibers, wire and plastic coverings around this core. Its VOD is around 6500 m/sec. Its external diameter is in the range of 4 to 10 mm (0.15 to 0.4 inches) with a core load in the range of 8–60 grains of PETN/ft or 10–15 gms/m. Special types of DCs are available with varying core loads such as: Seismic cord with 100 gr./ft for seismic work; RDX 70 Primacord with 70 gr./ft for oil well perforating; PETN 60 plastic with 60 gr./ft for oil well servicing; Plastic Reinforced Primacord with 54 gr./ft for under-water blasting; a Detacord with 18 gr./ft and B line with 25 gr./ft for secondary blasting. DC is safe to handle, extremely water resistant and capable of transmitting energy of a detonator to all points along its length. With DC detonators are not required to be put inside the holes. Some of blasting powders like ANFO requires a greater initiating effect through out its charge column, and DC can fulfill this requirement very well. It can be initiated by using a plain or electric detonator. To blast number of holes, the DC is inserted into the holes by lacing it to a primer cartridge or threading through a cast booster. The DC coming out from each of the holes (as a branch line) is connected to a common trunk line by strapping (taping), clove hitch or by a plastic connector. The detonator, plain or electric (of no. 6 strength) is lashed with tape, with its base pointing in the intended direction of travel of the detonation wave. The prevalent cord connections such as L joint, Double joint, Clove hitch joint and Lap joint have been shown in figure 5.6(e). Choice is governed by the blasting circuit or the design.
5.6.2.3 Igniter cords (IC)

It is cord-like in appearance and when ignited the flame passes along its length at a uniform rate. These are available with three rates of ignition; Fast – @ 11.5 sec/m (3.5 sec/ft, black in color); Medium speed @ 16–31 sec/m (5–10 sec/ft, green in color) and; Slow @ 50–65 sec/m (15–20 sec/ft, red in color). They can be used in surface mines, non-gassy and metalliferous underground mines, and tunnels for lighting any number of safety fuses in a desired sequence. IC connectors are required to use this cord, as shown in figure 5.5(d).

5.7 EXPLOSIVE CHARGING TECHNIQUES

Apart from the manual charging, use of ANFO loaders to charge the holes have been described in the preceding sections. Given below is the brief description of some other charging devices that are used.

Russian Drum type Charge Loader with mixer for Dry granulated explosive and slurry charging.

The important features include: Dry explosive from the hopper is fed to the mixing chamber where from it gets mixed with water, and conveyed though the hose to the
hole to be charged. The charging tube/hose is withdrawn gradually. A typical loader of this type has the following specifications:

- Hole dia. – 60 – 160 mm
- Loading depth, m – up to 50 m
- Inclination of hole – Any
- Av. productivity – up to 6 tons/hr.
- Air flow rate – 10 m³/min
- Reach in m – up to 250 m

5.7.1 WATER GEL (SLURRY LOADER)

It is available for loading cartridges of even less than 1-inch diameter. This product is liquid when manufactured but ‘gels’ after few hours. Use of pneumatic loading allows cartridges to the hole through the hose safely and quickly. It can be used for charging fans and rings. Given below are some its important features:

- Largest cartridge size = 38 mm dia.
- Loading hole size = 100 mm (max.)
- Charging up holes up to = 60 m length.
- Loading rate = 10 times faster than the conventional tamping stick method of loading.

These loaders are useful for the pneumatic loading of the watergel cartridges into vertically up ring and fan holes. Loading is uniform and consistent. Their applications in tunneling and drivage work for the holes up to 3 m lengths is limited as there is no saving in time but the charging of the holes is uniform, which in-turn, gives better results. The manufacturers of watergel explosives manufacture the Watergel cartridge loaders. DuPont is one of them.

In order to charge the explosives of different types in the shot hole, blastholes and big blastholes, the techniques use have been summarized in the line diagram shown in figure 5.7.

5.8 BLASTING ACCESSORIES

5.8.1 EXPLODERS

These are the machines designed to fire the electric detonators. As shown in figures 5.9 (b) and (c), these machines can be classified as Generator (magneto) (fig. 5.9(b))
type and Condenser discharge type. The generator type exploder works on the principle of an electric generator through which the current can be generated either by the rack bar mechanism or a twist handle mechanism. The current generated is used to fire the blasting caps connected in a circuit. In these types of exploders until certain minimum pre-fixed voltage is generated, it is not transmitted to the external blasting circuit, to avoid any misfire due to insufficient current (electric power). These exploders are manually operated so that power can be generated any time, but require, skill handling and use. Their repair is simple and these are useful to fire multi shots.

Condenser discharge types (fig. 5.9(c)) of exploders are designed for multi shots firing. Their basic source is either a low voltage dry cell battery or an electro magnetic generator. When a low voltage battery is used, first of all, the low voltage is converted to high voltage through DC to DC converter. The high voltage so generated charges the capacitor. When capacitor is fully charged a neon lamp indicates it. The voltage is discharged to the external blasting circuit connected to the exploder. It is light in weight and compact in size comparing with the magneto type of exploders of the same capacity. It is easy to operate but discharge of dry battery may affect its performance. One of its drawbacks is that the voltage from the capacitor are not fully discharged to the external circuit and some residual voltage remain in the capacitor, which in turn, may fire another circuit accidentally. The peak current can become high if few shots are fired, thereby, causing the fuse head explosion and side burst of the detonators.

Electric energy from power mains is also used now days when heavy blasting for underground metal mines or in surface mines is undertaken. For this purpose blasting cable is laid away from the service lines such as compressed air, water, ventilation ducts etc. Safety features such as a fuse box with main switch; a firing box and a short circuiting box are used when firing by mains. The circuits can be connected in series, parallel or series-parallel, as the case may be.
In electric firing it is essential to check for the resistance of the circuit, its continuity and presence of any short-circuiting, if any. This is achieved by the use of galvanometer and blaster’s multimeter. Galvanometer (fig. 5.9(a)) is used to check the resistance of the individual detonators and the resistance of the complete circuit. Multimeter can be
used to detect any current leakage in leg wires or blasting cables. Sometimes stray current is available due to leakage of current from the external sources other than the exploder. This may prove to be dangerous. The multimeter can detect this. A dry cell battery operates multimeter but its current is kept within the safe limits so that testing of the circuit and detonators can be carried safely. This is designed to test voltage, resistance (ohms) and current in milliamperes. It can be used to measure voltage output from an exploder.

A CIL Circuit tester, manufactured by CIL, is available in a handy cylindrical housing (fig. 5.9(d)). It can test circuit resistance upto 75 ohms. However, before use of any of these testing appliances in the mines, approval from the competent safety authorities should be obtained.

5.8.3 OTHER BLASTING TOOLS

The other blasting tools include: Crimper to crimp safety fuse into plain detonators; Pricker made of wood or a non ferrous material to prick into an explosive cartridge to prepare the primers; Knife to cut safety fuse; Stemming rod; Scraper; Flame safety lamp (in coal mines); Shot firing cable; Stop watch (when safety fuse is used) and suitable warning sign-boards or signaling arrangement.

5.9 FIRING SYSTEMS – CLASSIFICATION

Sequential firing: In many applications it is desirable to fire shots not instantly but in a sequential order. For different initiating devices/system this is achieved in the manner described below. The line diagram presented in figure 5.8 can summarize various shot firing systems described.

5.9.1 WHILE FIRING WITH A SAFETY FUSE

A safety fuse can be ignited by match-head, cigarette lighter or other lighters such as hot wire fuse type, pull wire fuse type etc. meant specially for this purpose. The other way is with the use of IC (Ignition cord) – which first of all ignited by any of these lighters. To achieve a sequential firing while using a safety fuse any of these practices can be adopted:

- Cutting fuse of different length and/or lighting them in a desired order.
- By connecting standard length of safety fuses (exactly of same length) with IC in a desired order.

5.9.2 FIRING WITH ELECTRIC DETONATORS

This is achieved by the use of long delay (half second) and short delay (millisecond) detonators. In coal mines non-incendive type detonators having copper tubes are used. The electric detonators charged in a face could be connected in series, parallel or series-parallel (fig. 5.6(f)). Series circuit should be preferred while firing upto 40 shots. If number exceed than this series-parallel connections should be made.
5.9.3 NON-ELECTRIC SYSTEMS

Using detonating cord: To achieve delay with DC a millisecond connector is used. Its construction details are shown in figure 5.5(d). The other non-electric system includes use of Anodes, Primadets, Nonel and Hercudets. Description of this system has been dealt in the preceding sections.

5.10 GROUND BLASTING TECHNIQUES

In order to blast the in-situ ground from its original place, apart from the use of different types of explosives and their initiating devices, the techniques outlined in figure 5.10, need to be applied. Selection of these techniques is based on the type of the drivage work to be undertaken. Details of these techniques have been described in the following chapters, wherever appropriate.

5.11 SECONDARY BREAKING

Generation of unwanted chunks of ore and waste rock while mining any deposit with the application of different blasting techniques is unavoidable. Dealing with these large chunks, known as boulders, either at their place of generation or on grizzlies is essential in order to facilitate the process of loading, hauling and crushing. This ultimately makes the process of muck handling safe, productive and economical (fig. 5.16(b)). Jamming of muck in the working stopes underground is another problem, which requires certain techniques to deal with.

Secondary breaking is the process of breaking the over sized boulders (lumps) which result during the primary blasting operations. Careful planning can minimize generation of these over sized boulders but it cannot be completely eliminated. The over sized boulder not only prevents the smooth flow of muck from the stopes to the draw points and ore-passes but many a times chock/block their mouth. Handling of over sized boulders gives undue strain to the loading and hauling equipment reducing their overall working life and efficiency. Optimum size of the muck eases the process of muck handling and ensures its smooth flow right from the stoping areas (or the place of its generation) to crushing units; improving overall productivity of a mine.
5.11.1 SECONDARY ROCK BREAKING METHODS

Over sized boulders when treated with the aid of explosives, the process is known as secondary blasting. But these boulders when brought to the grizzlies they are reduced to the required size either by manual hammering, or by any of the modern rock breakers – mechanical or electrical. The line diagram shown in figure 5.11 has presented this classification.

5.11.1.1 With the aid of explosives

5.11.1.1.1 Plaster shooting

In this process the boulder is shot by putting explosive over it and plastering it with a mud cap. Although the process gives higher powder factor comparing the pop shooting but its application can be justified in the stoping areas where less number of draw points are available, and time for pop shooting cannot be spared due to production pressure, or where pop shooting facilities do not prevail.

5.11.1.1.2 Pop shooting

The pop shooting ensures effective breakage of the boulder due to explosive concentration in the small diameter shot holes drilled in the boulder to be dealt with. In this technique in comparison to plaster shooting, better shattering effect with low powder factor can be achieved but large number of draw points should be available to perform continuous drilling and blasting operations.

5.11.1.1.3 Releasing jammed muck from the draw points

Jamming of the muck near the brows of the draw points in the troughs or funnels of the working stopes is a day-to-day problem in the mines. In order to release the jammed muck, in most of the cases, neither mucking equipment nor personal is allowed to approach it; hence, this is tackled from a remote and safe point. Bamboo blasting is a popular method applied to release or blast the jammed muck. As shown in figure 5.12(a), this technique involve tying the explosive cartridges to one end of a bamboo of the required size, and then putting it in contact with jam to be released, and blasting the charge which ultimately releases the jam.

Figure 5.11 Secondary rock breaking techniques.
Many times in-spite of repeated bamboo blasting, the jammed boulders do not roll down. In such circumstances at many of the mines, with prior approval of the safety authorities, the jam is released by the use of a small machine gun, riffles, throwing hand bomb or by firing a grenade launcher (fig. 5.12(c)).

5.11.2 WITHOUT AID OF EXPLOSIVES

5.11.2.1 Mechanical rock breaking

5.11.2.1.1 Manual breaking

In low output mines with surplus manpower this method of breaking boulders at grizzlies, with application of a sledgehammer manually is in practice even today. The method is slow and hazardous to the personal carrying this operation.
Another method of boulder breaking is the use of pneumatic hammer, which can be operated manually by one or two persons, is used on grizzlies. The pneumatic hammer in its mechanism is like a jackhammer except that it does not have the rotation mechanism and imparts only the hammering action. The operating compressed air pressures ranges from 4.5 to 6 kg/cm².

5.11.2.1.2 Mechanical rock breakers

In mechanized mines for smooth flow of the muck to keep the grizzlies clean, especially those which are feeding the ore passes or the primary crushers, is an important task to be planned. Installation of mechanical breakers on such grizzlies has become a routine feature throughout the world. As per the output and strength of rock any of rock breakers (fig. 5.12 (e) & (f)) described below are used.

5.11.2.1.3 Hydraulic rock breakers

In this type of breakers hammering as well as boom movements are carried out with application of hydraulic power. The machine is either mounted on a concrete base or can be installed on a mobile van. A typical breaker of this type, as shown in figure 5.12(e), has these details: The breaker consists of a set of booms each articulated by hydraulic cylinders with a maximum horizontal reach of 8 m and maximum vertical reach up to 6 m. The boom can swing up to 270°. The front boom has a handle capable of 180° rotation. The hammer attached to boom is designed for 6 blows/sec with an impact energy of 179 kg-m. per blow. The demolition tool attached is 100 mm in dia. and 600 mm long. The oil pump is run by 40 H.P. electric motor. The breaker is well suited to medium-hard rocks.

5.11.2.1.4 Teledyne rock breaker

This is widely used breaker in mines for its application on grizzlies in underground as well surface mines (fig. 5.12(f)). It is suitable for hard rock and differs from the hydraulic breaker by having the hammering action pneumatically. Mechanical rock breaking is safer, efficient and economical and in use very widely.

5.11.2.2 Electrical rock breaking

The electrical energy can be converted into a thermal, magnetic and mechanical power, which in this case is utilized to fracture the rock. Every rock mass depicts certain electrical properties such as resistance, inductance, and electrolytic conductivity in varying degrees. Some rocks can be classified as semi-conductive with respect to their ability to break electrically. This means they become conductive at some critical voltage level. There are several methods to induce conductivity.

The metallic ores such as magnetite, hematite, pyrite, galena, copper ores, titanium and many others increase their conductivity at some critical voltage level and carry the current through a network of conductive zones. Heating of the rock a few hundred degrees takes place only in isolated areas within the rock mass. The average temperature during fragmentation would increase by only a few degrees.

5.11.2.2.1 Rock breaking by the use of high frequency current

This method of rock breaking is based on the following principle (fig. 5.13). Current of certain frequency is passed by the direct contact with the rock subjected to disintegration. Because of the action of high frequency electric field and of the conducting
EXPLOSIVES AND BLASTING

(a) Schematic presentation for rock breaking by the use of high frequency current

(b) Schematic presentation for rock breaking by current of high & industrial frequencies simultaneously

(c) Schematic presentation for rock breaking by high frequency current with impulses

(d) Underground installation for secondary breaking by electrothermal method

Legend:
1 - Tippler
2 - Inclined portion of vibrator
3 - Vibrator
4 - Horizontal part of vibrating screen
5 - Storage
6 - Electrodes
7 - Coaxial feeder cable
8 - High frequency current generator

(e) Underground installation for secondary breaking by electrothermal method. Use of vibrating feeder shown

Legend:
1 - Vibrating feeder
2 - Belt conveyor
3 - Vibrating screen
4 - Vibrator
5 - Contact electrodes
6 - Feeder cable

(f) Underground installation of an electric rock breaker before feeding underground crusher

Figure 5.13 Secondary breaking electrically at underground installations.
current, the rock situated between contacts is heated rapidly and undergoes thermal disruption. Dielectric rocks or rocks of poor conduction thus becomes the conductors through the breakage channels. Continued heating of the current conducting channels generates thermoelectric tension in the rock that is sufficient to break it. The conditions of thermal breakage in various rocks depend upon their electrical and magnetic properties. Thus, each type of rock responds to a certain current frequency, usually to the order of 8000 Hz. The scheme corresponding this method is shown in figure 5.13(a).

The oscillatory circuit consists of inductance \( L_1 \) and capacitance \( C_1 \). The winding of high frequency transformer consists of inductance \( L_1 \) and \( L_2 \). The contact terminals are connected to the egress of secondary winding, made up of two to four turns, with the aid of coaxial cable. The electric circuit is formed by secondary winding \( L_2 \), the contact terminals and the block of rock.

Figure 5.13(b) shows principle of installation for rock breaking by simultaneous use of high and industrial frequency currents. In this case for electrical rock breaking and formation of current conducting channels, high frequency current is employed, whereas, to break the rock, alternating current of industrial frequency together with high frequency current are used. The inductance \( L_2 \) and capacitance \( C_2 \), and the contact terminals constitute the charged circuit whereas the inductance \( L_1 \) and capacitance \( C_1 \), the oscillatory circuit of high frequency.

Figure 5.13(c) shows the electrical set up of the rock breaking installation using high frequency current with impulses. The method consists of use of high frequency currents for the creation of channels whereas the disintegration of the rock is achieved by impulses received from the capacitor. Voltage of high frequency is obtained from the transformer \( L_1–L_2 \) through capacitance \( C_2 \). At the moment of the formation of breakage channels in the rocks, the relay RT interrupts the charge network whereas the capacitor \( C_1 \) is discharged through the gap \( D \) in the rock causing it to break.

Figure 5.13(d) shows a scheme of automation of secondary breakage in a crusher with tippler. As shown in the section A-A five or six electrodes are suspended from the roof of the compartment by an insulating element for breakage of boulders.

Figure 5.13(e) shows the arrangement of crusher for secondary breaking by crushing with a vibrating feeder. It is always advantageous to carry out secondary breakage by combination of two methods: mechanical (jaw crushers) and Electro-thermal (by high frequency current). This combined method of secondary breakage is termed as thermo-mechanical. Figure 5.13(f) shows an underground installation of rock breaker, the technical data for such a breaker are as under:

- Electrical load – 100 KVA; Line voltage – 6000 V; Max. voltage – 2460 V; Frequency – 50 Hz.
- Electrode dia. 75 mm; Electrodes – graphite; Max. size of boulder – \( 3 \times 3 \times 3 \) m
- Energy – 4.38 KWH/m³.

The electric rock breaking studies have shown the power consumption of various sizes of rock fragments as under:

- 1 KWH or less/ton. for obtaining fragment size in the range of 200–500 kg.
- 3–5 KWH/ton. for obtaining fragment size in the range of 200–50 kg.
- 0–15 KWH/ton. for obtaining fragment size less than 25 cm.

The electrical rock breakers are in use in some of the mines in Russia, US and many other countries. This has added advantages of economy, generation of no noise, dust and flying fragments.
5.11.2.3 **Hydraulic boulder splitter**

Atlas Copco has developed a unit, CRAC-200, with a hydraulic cannon that shoots a water projectile into drilled holes, as shown in figure 5.12(d). The high water pressure created in the hole splits the rock. The unit consists of a rock drill, a water cannon and a feed mechanism. This set can be fixed on floor or put on a mobile van. The splitting operation consists of drilling a hole of 34–36 mm dia. of 0.8 m depth. The cannon is swung into position over the drilled hole and then it is charged with 1.8 lit. water. The cannon forces the water projectile into the hole causing the boulder to split.

5.12 **USE, HANDLING, TRANSPORTATION AND STORAGE OF EXPLOSIVES**

Explosive is a commodity that cannot be allowed to handle by any one else than an authorized person by the government, as it requires, a special skill for its handling, use, transfer and storage, apart from the security reasons. Proper accountability is kept at any stage, right from receiving from the manufacturer up to its end use, to avoid any pilferage. Explosive is very sensitive to shock, impact, jolt, friction, ignition, spark or tampering, hence the important guideline is that, all precautions must be taken against all these factors during its storage, transportation, handling and use. To safeguard against all these dangers, every country has its own rules and regulations. One will find that these regulations have been formulated by taking into consideration of these guidelines.

5.12.1.1 **Magazine**

It is a place where an explosive is stored (fig. 5.14(a)). It is constructed using specified specifications by the safety authority of any country and need to comply with certain basic design considerations. It should be located in an isolated and remote area. May be an area surrounded by hills etc. or by artificially created earth mounds. The electric over-head lines should be at least 91 m (300 ft. or as specified by the safety authority) away. In general, the following guidelines are followed while constructing a magazine:

- Roof should be leak proof and the floor damp proof. Dimensions should be chosen as per the capacity.
- The doors and window should be of sufficient strength and constructed by fitting inner lining of wood. No iron nail, hinge etc. should be used. All hinges, locks etc. should be made of brass or any non-ferrous material such as copper, bronze etc. The idea is that any material that can produce spark should not be used as a tool or construction material in the direct contact with the explosive. All doors should open outwards.
- Magazine must be fitted with an effective lightning conductor system and all iron and steel used in the construction of doors etc. should be properly bonded and earthen. Earthling should be checked periodically.
- Provision for water and fire extinguishers should be made.
- ‘Z’ type of ventilators should be provided near the floor and roof in the walls.
- Detonators must be stored in a separate annex, which can be accessed separately. Wall between explosive and detonator compartments should not be less than 0.9 m (3 ft.) thick (or as specified by the safety authority).
- All detonators, explosive containers and fuse box etc. should be stored on wooden benches.
- Magazines should be fenced properly from all sides.
Provision for its guarding by watchmen, round the clock, in rotation must be made.
Only authorized person should access the magazine.

In figure 5.14(a) layout of magazine having almost all the features as described above has been shown. In figure 5.14(b) an ANFO mixing plant at a Copper Mining Complex in Oman has been shown.

Special vans are used to transport explosives. Containers of special design are used to transport explosives from the magazine to underground up to its place of use. Usually these explosive containers are kept in a special underground station, known as ‘Reserve Station’ before carrying them to the face. The blaster transports detonators separately.
5.13 EXPLOSIVE SELECTION

Selection of an explosive requires a review of the type of explosives available, size and type of blastholes usually drilled, blasting theories and techniques available. Experience of the planner and past performance also plays an important role.

While blasting of any kind, the rate of release of energy, which is measured as velocity of detonation is of prime importance. The relation between the borehole dia. and velocity of detonation varies as per blasthole dia. for any explosive, as shown in figure 5.3(a). Also there is definite relation between V.O.D and explosive density, as shown in figure 5.3(b). Thus, to a particular dia. of blasthole a matching V.O.D can be selected and for a desired V.O.D range, a commercial explosive of a particular density can be chosen. But during this selection: the locale, fume characteristics, degree of fragmentation, type of profile and, above all, the cost of explosives will be the main considerations.

Here the locale signifies use of explosive for surface or underground mines or tunnels, and in underground also whether for development or stoping operations. In an underground situation fume characteristics will play a very crucial role whereas in surface mines this may not be major consideration. In underground coal mines protection against the fire and explosion of the methane gas due to blasting will be the main criteria. The strength of rock, degree of fragmentation and type of free face available during a particular blast mainly govern explosive strength required. In u/g non-coal and metal mines, and tunnels where heavy blasting can be undertaken, reduction in blast vibrations plays a significant role.

A proper explosive’s selection, its judicious utilization and quality work in the blasting operations makes the process safer, economical and productive.

5.14 BLASTING THEORY

As shown in figure 5.15(e), when a cylindrical charge is fired in a blast-hole, the detonation moves up the explosive column from the primer, a high pressure stress wave travels into rock mass. The positions of detonation waves and stress waves are as shown in this figure at different times. A horizontal section through this charged blast-hole, figure 5.15(b), shows how the area surround hole is divided into radial fractures at different point of time (zones 1 to 5) by the compression shockwaves. These waves from the free face are reflected back as tensile stress waves [fig. 5.15 (b) I – A, B, C; II, III]. Since rocks are weaker in tension than compression, these tension waves cause more and more fracture to rock mass (fig. 5.15 (c)). Desired fracture or fragmentation will occur when there is proper burden and the rock mass subjected to this phenomenon is free from the natural discontinuities such as fractures, joints etc. In any blasting operation only 3% of the explosive energy is used by the compression wave and the boulders will be generated if this energy is not sufficient to return back after traveling up to the free face. The compression waves only enlarge the radial cracks but tension waves cause the rock to fragment.

The rapid expansion of the gases in the blasthole causes ‘flexture or bending’ (fig. 5.15(c) and (d). The gas pressure also causes radial crack through the rock mass up to the burden and then its displacement. Figure 5.15 illustrates all these mechanisms.

For the spherical charge the crater theory as described in section 13.10 should be used.
5.15 DRILLING AND BLASTING PERFORMANCE

Performance of rock breakage or ground excavation with the aid of explosives can be assessed taking into consideration of the indicators listed below.

5.15.1 PERCENTAGES PULL

It is the ratio of length of round drilled to the effective linear advance obtained after blasting. Pull below 100% reflects inefficient drilling and blasting. This adversely affects the powder factor, which is the amount of explosive required per unit of rock blasted (i.e. explosive in kg/t or kg/m^3), and drills factor, which is the rock yield/m (i.e. t/m) of drilling.
5.15.2 OVER-BREAK FACTOR

After blasting the face an additional breakage at the face is usually obtained than the designed one. Over break factor is the ratio of the area of the face after blasting, including the over break, to the designed one. Over break has adverse effects with regard to the face stability, cost of support, face configuration and amount of muck generation due to dilution caused. Contrary to this is under-break that can result formation of loose, irregular face configuration, and poor drill and powder factors. Exact
confirmation of the blasted face with the designed one reflects skill of the operators. It gives optimum results.

5.15.3 DEGREE OF FRAGMENTATION

Generation of over sized or under sized chunks/rock pieces has an overall impact on cost. This parameter has a direct relation with unit operations such as drilling, blasting, mucking, transportation and primary crushing. Hence, an optimum size of fragment is always warranted. Relation between costs of these operations w.r.t. degree of fragmentation is illustrated in figure 5.16.9

5.15.4 OVERALL COST

The overall efficiency of drilling and blasting should be looked in totality both during development and stoping operations. To choose an alternative means of rock breakage by any means other than drilling and blasting, overall cost of the operations should be calculated and compared. Mathematical relation equation (5.5)\(^1\) can be used for this purpose.

\[
C_{tot} = C_d + C_{b1} + C_{b2} + C_m + C_h + C_{chu} + C_{mis}
\]

(5.5)

Where as: \(C_{tot}\) total cost of mining/t of ore; and \(C_d, C_{b1}, C_{b2}, C_m, C_h, C_{chu}, C_{mis}\), are the cost/t of drilling, primary blasting, secondary blasting, mucking, haulage, hoisting, primary crushing and miscellaneous respectively.

Use of \(^+/−\) signs should be made when comparing the costs of two systems w.r.t. the unit operations used in this relation. \((+\) Sign, if the cost is excessive than the one with the aid of explosives and \((-\) sign, if it is less than it. In this manner an overall cost difference between various systems can be assessed and efficiency of the system can be judged.

Natural conditions vary from mine to mine (or one tunnel to another) and even within the same mine and, therefore, it should be bear in the mind that establishment of proper drilling and blasting practices and selection of a suitable method, design and equipment to perform these operations is a matter of experience of the planner and their proper execution through field trials and test results.

REFERENCES


