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TEKNIK PELEDAKAN

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Subjects

1. Use Forms of Explosives
2. Estimating Properties of Explosives
3. Explosive Selection Criteria
4. Blasting Accessories
5. Initiation and Priming Systems

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6. Nonelectric Initiators
7. Qualitative Description of a Shock Wave
8. Fracture Mechanism in Blasting of Rock
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Subjects

21. Blasting in Underground
22. Overbreak Control
23. Perimeter/Contour and Controlled Blasting
24. Environmental Effects of Blasting
25. Blasting Safety

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Estimating Properties of Explosives

https://www.miningmagazine.com/supply-chain-management/news/1371861/riogel-causing-latam-blast

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Properties of Explosives

1. Strength and Energy
2. Cohesiveness
3. Detonation Velocity (VOD)
4. Density
5. Detonation Pressure and Explosion Pressure
6. Borehole Pressure

Properties of Explosives

7. Stability
8. Water Resistance
9. Sensitivity
10. Detonation Transmission
11. Desensitization
12. Temperature Resistance

Properties of Explosives

13. Fumes
14. Inflammability
15. Safety in Handling
16. Storage Qualities
17. Medical Aspects
18. Permissibility

Introduction

Conventional explosives and blasting agents have different **properties** which characterize them and are used in assessing them for correct selection, depending upon the type of blasting to be carried out and the conditions under which it will be put into operation.

Introduction

The **selection of the type of explosive** to be used for a particular task is based on 2 (two) primary criteria.

1. The explosive must be able to function safely and reliably under the environmental conditions of the proposed use.
2. The explosive must be the most economical to use to produce the desired end result.

Introduction

Before any blaster selects an explosive to be used for a particular task, one must determine which explosives would **best suit the particular environment** and **the performance characteristics which will suit the economy** of the job.

Introduction

Hence, it is appropriate that knowledge about properties of explosives is obtained so that type and quantity of explosives used can be decided *based on* its ability to function under the specified conditions and achieve the objectives efficiently.

Introduction

The **properties** of each group of explosives also give prediction of the probable results of fragmentation, displacement, and vibrations.

Introduction

The most important characteristics are: strength and energy developed, detonation velocity (VOD), density, detonation pressure, water resistance, and sensitivity.

Other properties which affect their use and must be taken into account are: fumes, temperature resistance, desensitivation by external causes, etc.

Introduction

Numerous other properties can be specified for explosives but have not been included here because of their lack of importance to the field blaster.

1. Strength and Energy

From the industrial application point of view, the **strength** is one of the most important properties as it defines the energy available to produce mechanical effects. **Strength** refers to the energy content of an explosive which in turn is the measure of the force it can develop and its ability to do work.

1. Strength and Energy

There are different terms to express the strength of an explosive. In the original dynamites (straight dynamite), the percentage of nitroglycerin was the parameter to measure the strength.

1. Strength and Energy

Later, with the partial substitution of nitroglycerin with other products and the carrying out of comparative laboratory tests, the terms were changed to **Relative Weight Strength** and **Relative Bulk Strength**.

1. Strength and Energy

This way, it is frequent to refer to the strength of an explosive in so much **percent** of another taken as a *standard*, such as pure gelatin dynamite, ANFO, etc., which has the assigned value of 100.

1. Strength and Energy

There is no standard **strength measurement method** universally used by the explosives manufacturers.

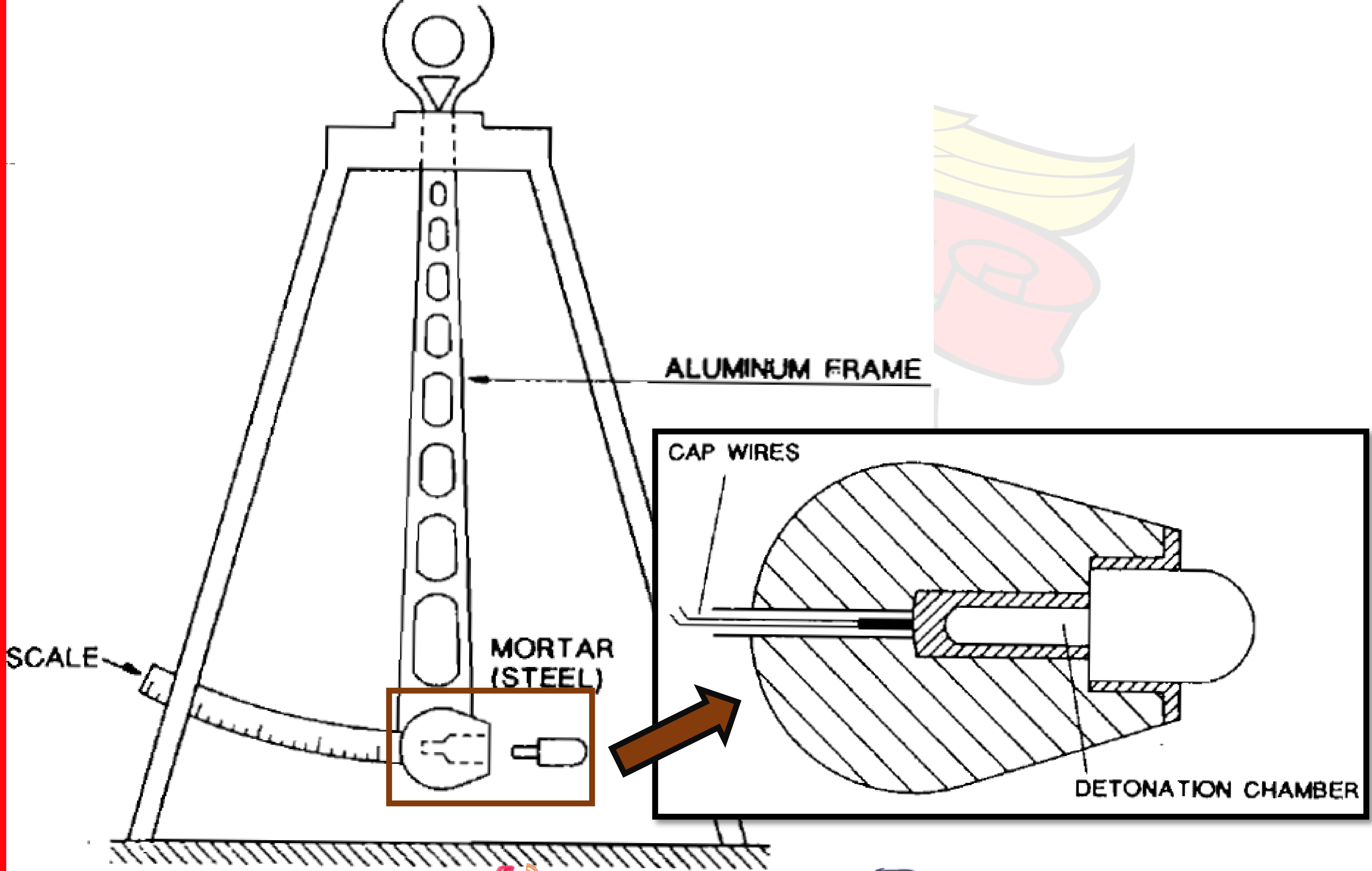
Strength ratings are *misleading* and *do not accurately* compare rock fragmentation effectiveness with explosive type.

1. Strength and Energy

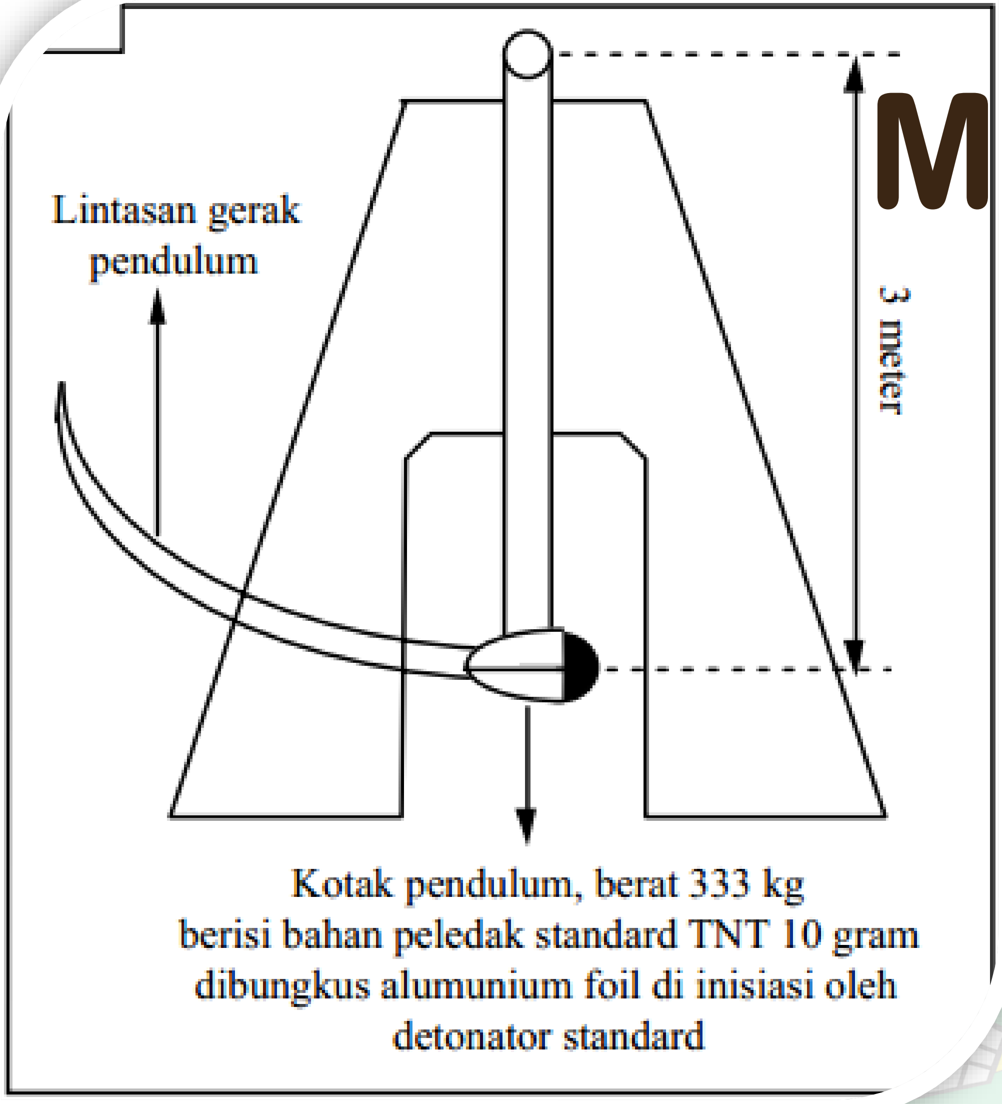
There are various practical methods to measure the strength or the available energy of an explosive.

1. Traulz test
2. Ballistic mortar test
3. Seismic Strength test
4. Crater charges test
5. Cylinder compression test
6. Plate dent method
7. Double pipe test
8. Underwater test
9. Empirical equations

Ballistic Mortar Test



Ballistic Mortar Test



Kotak pendulum, berat 333 kg
berisi bahan peledak standard TNT 10 gram
dibungkus alumunium foil di inisiasi oleh
detonator standard

Ballistic Mortar Test

This consists in *comparing* the propulsion of a steel mortar mounted upon a ballistic pendulum by the effect of the gases when a charge of *10 g of explosive is detonated*.

Ballistic Mortar Test

The T.B.M. index is calculated from the equation:

$$T.B.M. = 100 \times \frac{1 - \cos \alpha}{1 - \cos \beta}$$

where α and β are the angles registered in the recoil deflection of the pendulum corresponding to the test explosive and the standard explosive.

Underwater Tests

Underwater tests have been used to determine the shock energy and expanding gas energy of an explosive. These two energy values have been used quite successfully by explosive manufacturers in predicting the capability of an explosive to break rock.

Underwater Tests

Underwater tests have been found to be useful tool in evaluating relative strengths of various explosives provided that these tests are carefully interpreted in conjunction with theoretical calculations and field performance.

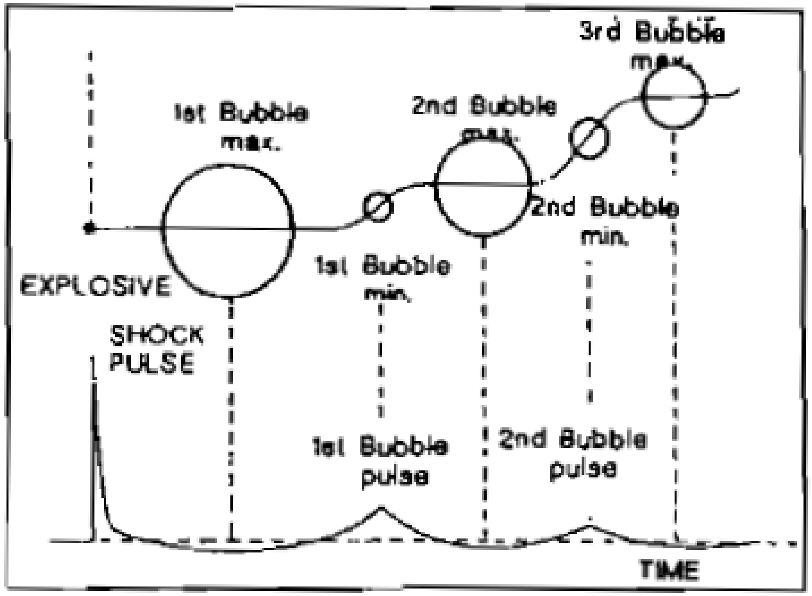
Underwater Tests

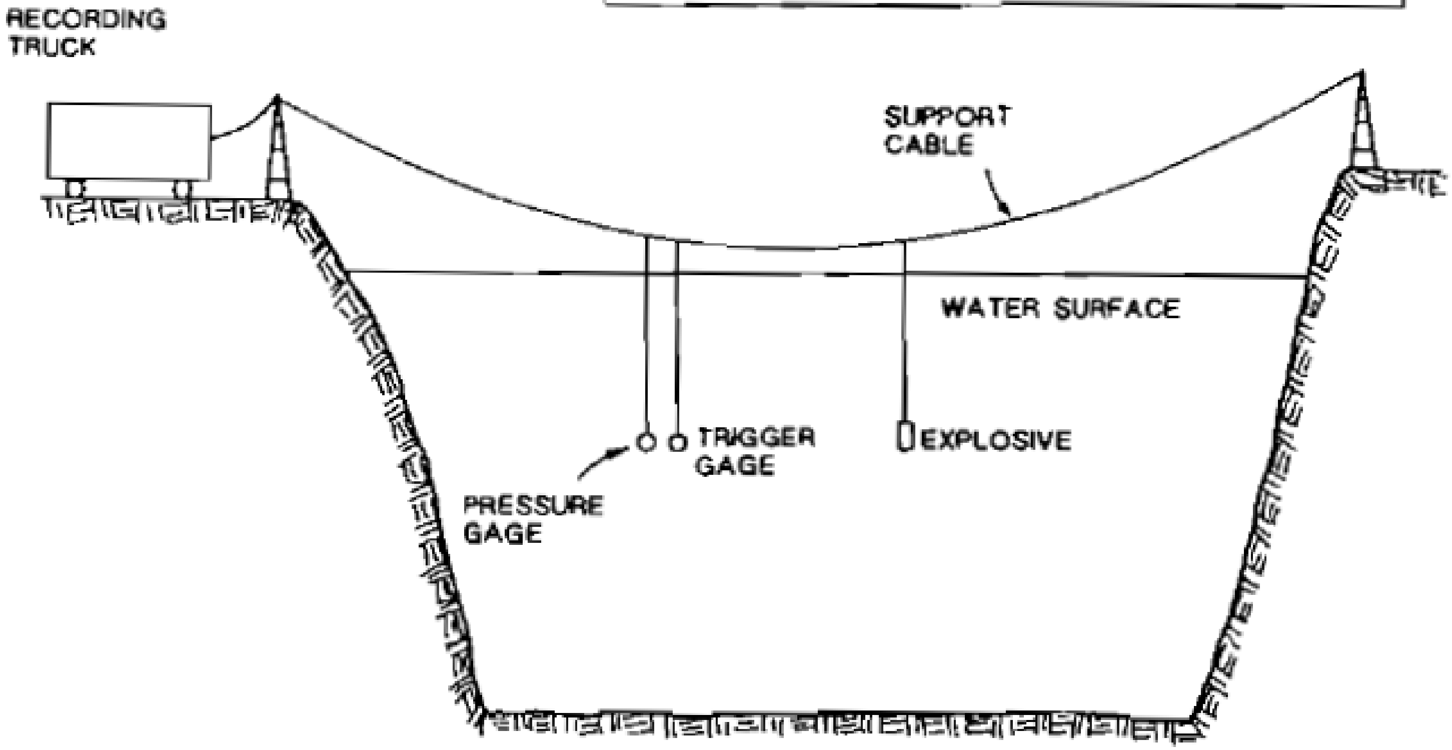
This technique to quantify energy released by an explosive was suggested by Cole in 1950s, and it is characterized as being one of the most complete as it permits tests with charge geometries similar to those in blastholes.

Underwater Tests

Another feature is that it permits the separate calculation of the energy linked to the **strain wave (Strain Energy-ET)** and **the energy of the detonation gases (Bubble Energy-EB)**, as well as the possibility of evaluating the influence of the initiation system on the energy released by an explosive.

Underwater Tests





Underwater Tests

Experience has shown that **bubble energy** values frequently *overrate* an explosive's ability to fragment hard rock, but are *more closely* related to the capability of displacing weak rock.

Underwater Tests

This method is very useful for comparing the yields of similar explosives under the same testing conditions. At the moment, it is <u>the most used procedure in evaluating explosive energy</u>, because *with exception of the Thermic Energy*, the rest is reliably assessed.

Empirical Equations

The equation used to calculate the Relative Weight Strength is

$$PRP = \left(\frac{\rho_e \times VD^2}{\rho_o \times {VD_o}^2}\right)^{1/3}$$

where ρ_e = density of the explosive (g/cm^3),

VD = detonation velocity (m/s), ρ_o and VD$_o$ refer to the standard explosive.

1. Strength and Energy

Even these new tests and calculations, when considered independently of one another, do not predict an explosive's effectiveness in all cases.

To date, no single test or calculation can predict the blasting action of a commercial explosive, principally because of **the complex nature of the materials** being blasted.

1. Strength and Energy

The performance of an explosive is not determined simply by knowing the total energy released by the explosive. *It depends also* upon the rate of energy release and how effectively the energy is utilized in fragmenting and moving the material being blasted.

1. Strength and Energy

Both the explosive properties and the properties of the material being blasted influence the **effectiveness of an explosive**.

Theoretical Energy

1. **Heat of Explosion, Q**

   This energy represents the total thermal energy and includes the heat retained by products of detonation at atmospheric pressure.

2. **Expansion Work (EWK)**

   The energy of the detonation products which be examined at different temperature and pressure states of expansion, ending with gas expansion to atmospheric pressure.

Theoretical Energy

In some cases, however, EWK *may be* higher than Q because of the change in reaction products with expansion.

Energy tied up in the expanded detonation products is *not a useful blast energy*.

2. Cohesiveness

Cohesiveness is defined as the ability of the explosive to maintain its original shape.

3. Detonation Velocity (VOD)

Detonation velocity refers to the speed with which the detonation wave is propagated through the explosive and, therefore, is the parameter which defines the rhythm of energy release.

3. Detonation Velocity (VOD)

It ranges from about **5,500 to 25,000 fps** (1 ft = 0.3048 meters, hence it ranges from about **1,676 to 7,620 meters**) for products used commercially today.

3. Detonation Velocity (VOD)

A **high detonation velocity** gives the shattering action that many experts feel is necessary for difficult blasting conditions, whereas **low-velocity products** are normally adequate for the less demanding requirements typical of most blasting jobs.

3. Detonation Velocity (VOD)

Detonation velocity, particularly in modern dry blasting agents and slurries, may vary considerably depending on field conditions.

3. Detonation Velocity (VOD)

The factors that affect VOD are:

- ✓ charge density,
- ✓ diameter,
- ✓ confinement,

3. Detonation Velocity (VOD)

- ✓ initiation or priming

It is essential that **adequate priming** is ensured so that the explosive may reach its maximum velocity as quickly as possible. *Inadequate priming* can result in the failure of the explosive to detonate, a slow build-up to final velocity, or a low velocity detonation (which amounts to deflagration);

3. Detonation Velocity (VOD)

✓ aging of the explosive

(the process of change in the properties of a material occurring over a period, either spontaneously or through deliberate action).

3. Detonation Velocity (VOD)

Detonation velocity can often be increased by the following:

1. Using a *larger charge diameter*.
2. *Increasing density* (although excessively high densities in blasting agents may seriously reduce sensitivity).

3. Detonation Velocity (VOD)

3. *Decreasing particle size* (pneumatic injection of AN-FO in small diameter boreholes accomplishes this).
4. Providing *good confinement* in the borehole.

3. Detonation Velocity (VOD)

5. Providing a *high coupling ratio* (**coupling ratio** is the percentage of the borehole diameter filled with explosive).
6. Using a *larger initiator or primer* (this will increase the velocity near the primer but will not alter the steady state velocity).

3. Detonation Velocity (VOD)

There is a difference of opinion among experts as to how important detonation velocity is in the fragmentation process. It probably is of *some benefit* in propagating the initial cracks in <u>hard, massive rock</u>. In the <u>softer, prefactured rocks typical</u> of most operations, it is of *little importance*.

3. Detonation Velocity (VOD)

Velocity determinations are made by measuring the time required for the detonation wave to travel a measured distance longitudinally through a column of the explosive.

3. Detonation Velocity (VOD)

There are diverse methods to measure VOD, among which the following are emphasized:

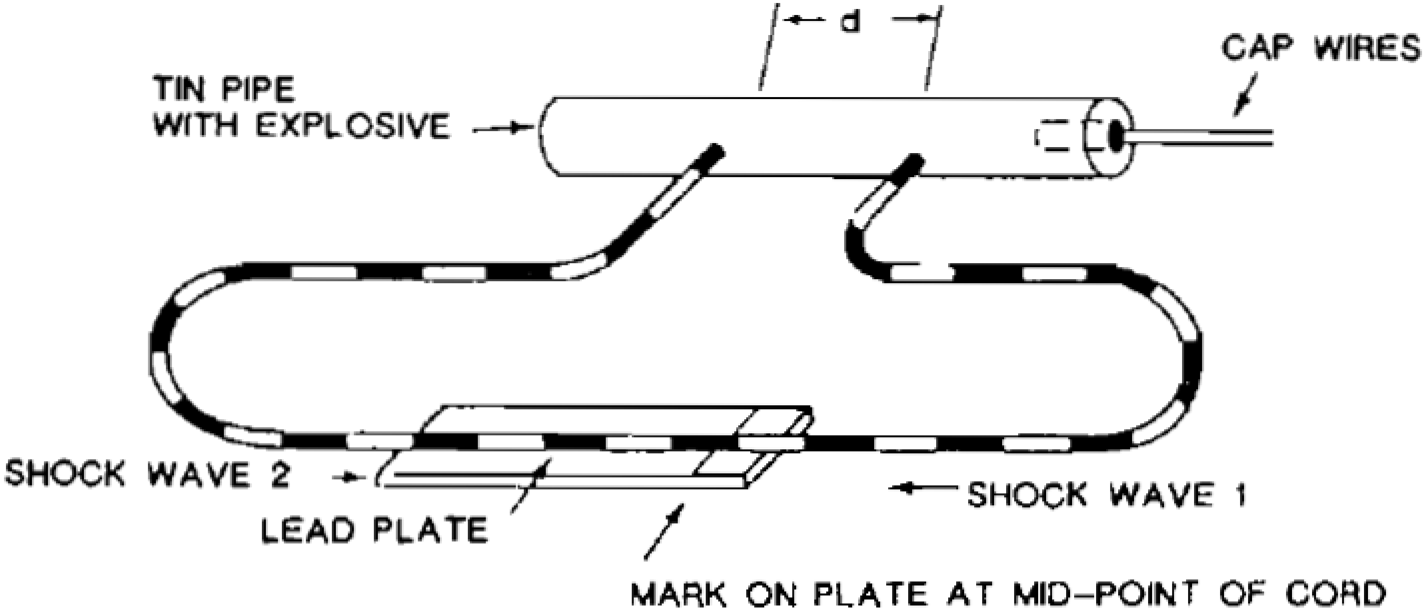
- D’Autriche method
- Kodewimetro
- Chronograph

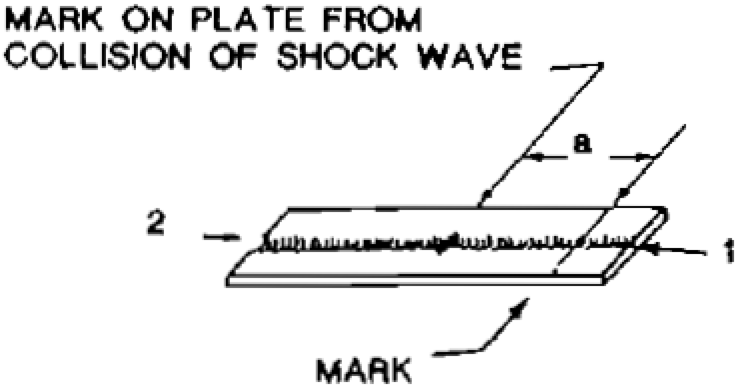
D’Autriche Method

This method is based upon comparing the VD of the explosive with the velocity that is already known of a detonating cord (VD_c). Therefore, the VOD_e of the explosive is determined from:

$$VD_e = \frac{VD_c \times d}{2a}$$

D’Autriche Method





$$VD_e = \frac{VD_c \times d}{2a}$$

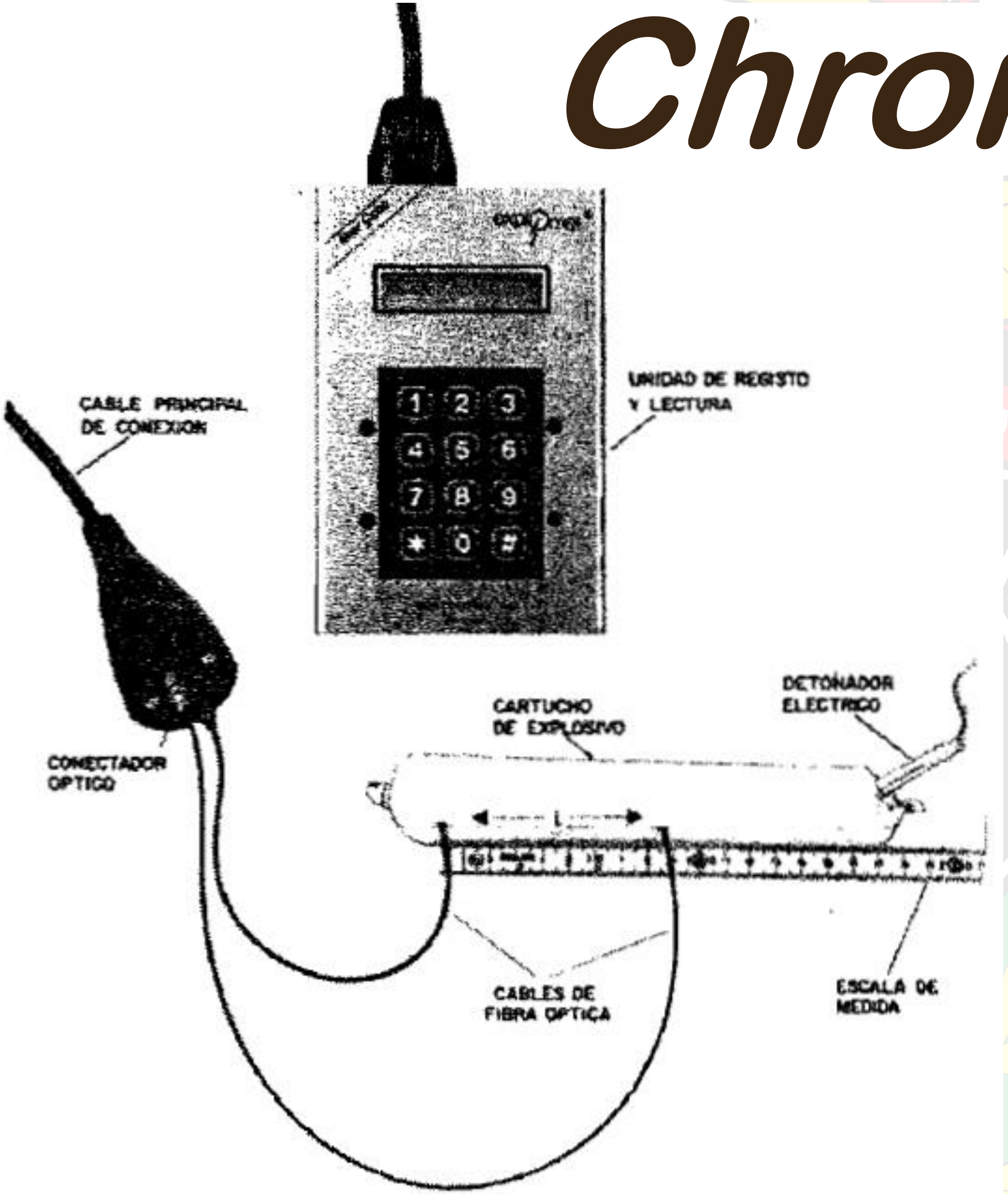
Kodewimetro

This is based upon the variation in resistance of a cable probe that goes through an explosive column axially. By means of special equipment called **Kodewimetro**, connected to an oscilloscope, the voltage variation, which is proportional to the resistance, is measured while maintaining a constant current intensity in the circuit. As the detonation wave advances along the length of the explosive, the electric resistance diminishes and the VOD can be determined from the stress to which it is proportional.

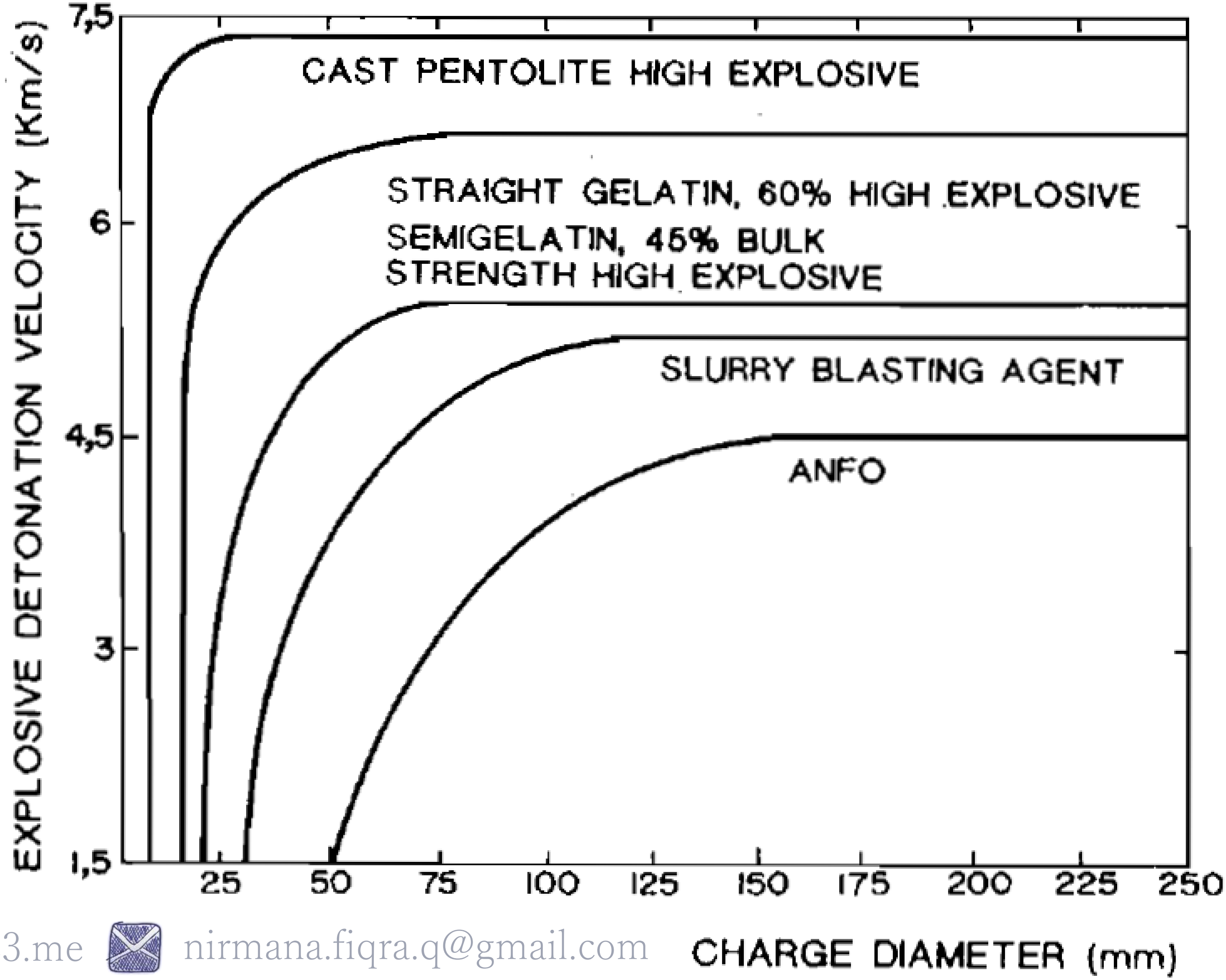
Chronograph

From two sensors introduced in the explosive and placed at a determined distance the VOD can be calculated by measuring the activation time of each sensor. At the moment, there are instruments that are capable of giving VOD directly and with high precision. The sensors can be electric or, more modernly, of optical fiber.

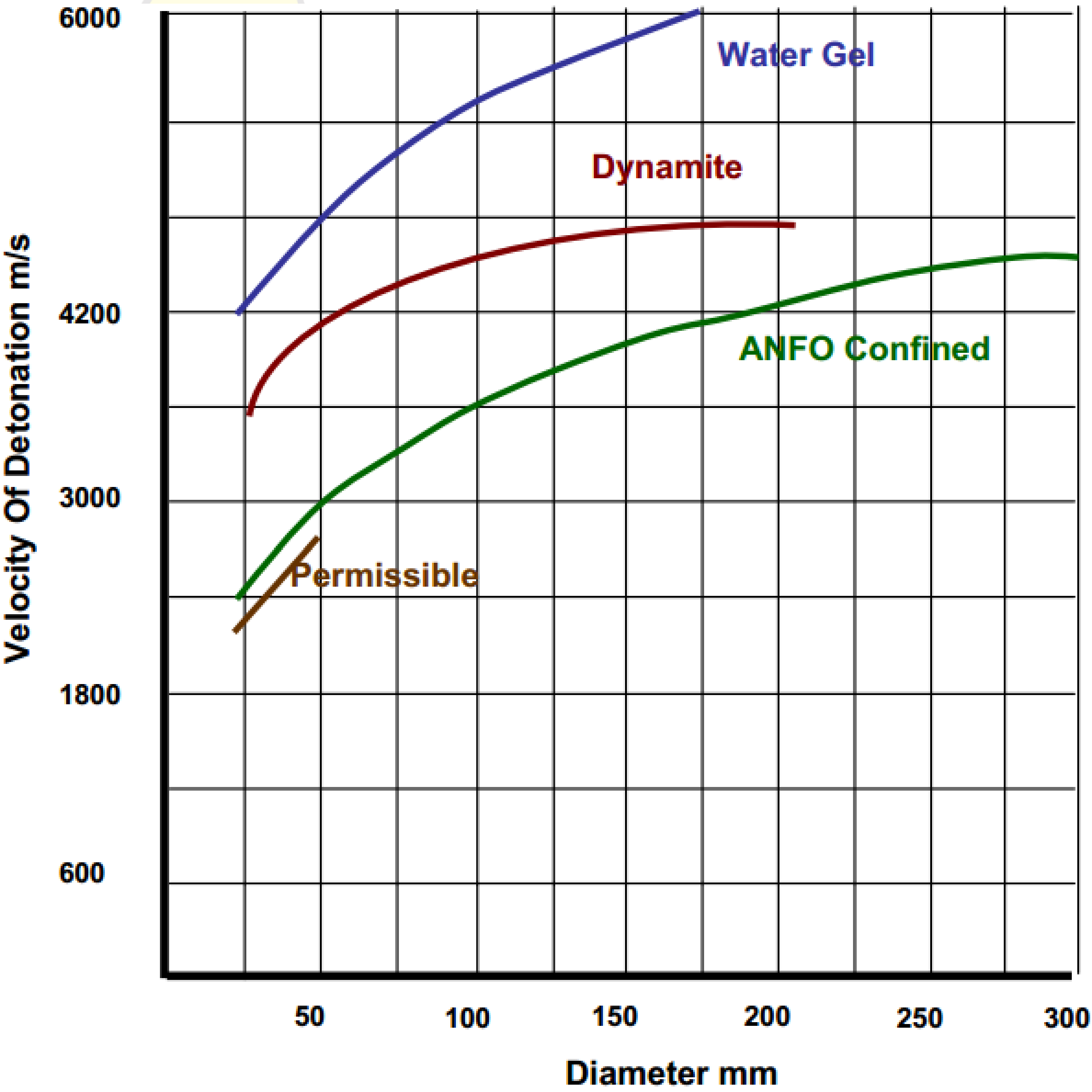
Chronograph



Influence of the charge diameter upon the detonation velocity (Ash, 1977)



Effect of explosive diameter on velocity of detonation (Bhandari, 1997)



3. Detonation Velocity (VOD)

Type	Density (gr/m^3)	VOD (m/s)		
		De = 1.25 inch	De = 3 inch	De = 9 inch
Granular Dinamit	0.8-1.4	2,240-6,080		
Gelatin Dinamit	1.0-1.6	3,840-8,000		
Cartridge Slurry	1.1-1.3	4,160-6,080	4,480-6,080	
Bulk Slurry	1.1-1.6		4,480-6,080	3,840-6,080
Poured ANFO	0.8-0.85	1,920-2,240	3,200-3,520	4,480-4,800

3. Detonation Velocity (VOD)

Type	**Density (gr/m^3)**	**VOD (m/s)**		
		De = 1.25 inch	De = 3 inch	De = 9 inch
Packaged ANFO	1.1-1.2		3,200-3,840	4,480-4,800
Heavy ANFO	1.1-1.4			3,520-6,080

3. Detonation Velocity (VOD)

Every explosive also has a critical diameter which is the minimum diameter at which the detonation process, once initiated, will support itself in the column. In diameters *smaller* than the critical diameter the detonation of the explosive will not be supported and will be extinguished.

4. Density

The density of an explosive is important because explosives are purchased, stored, and used on a **weight basis**.

The density of the majority of explosives varies between 0.8 and 1.6 g/cm^3 and, as in detonation velocity, the greater it is, the more breakage it provides.

4. Density

In blasting agents, density can be a critical factor because, if it is very low, they become sensitive to the detonating cord which begins to initiate them before the detonation of the primer cartridge; on the other hand, if it is very high they can become insensitive and not detonate. That limit density is called **Death Density**.

4. Density

Density is *normally* expressed in terms of specific gravity, which is the ratio of explosive density to water density.

The specific gravity of the explosive is *commonly* used as a tool to approximate strength.

Typical Specific Gravity Values for Explosive Products

Type	Specific Gravity
Granular Dynamite	0.8-1.4
Gelatin Dynamite	1.0-1.7
Cartridged Slurry	1.1-1.3
Bulk Slurry	1.1-1.6
Air Emplaced ANFO	0.8-1.0
Poured ANFO	0.8-0.9
Packaged ANFO	1.1-1.2
Heavy ANFO	1.1-1.4

Typical Specific Gravity Values for Explosive Products

Type	Specific Gravity
Watergels and emulsions	0.8-1.5
Cast boosters	1.6

4. Density

The prime purpose in varying the density of commercial explosives is to enable the total energy charge in a borehole to meet particular field conditions.

4. Density

In many cases, such as **in mining hard ore and driving tunnels through hard rock** it is necessary to use dense gelatins or high density blasting agents in order to break the burden.

4. Density

In other instances, as in production of certain ore or stone where a **high percentage of lump is desired**, the charges are distributed in the borehole with low density gelatins or blasting agents.

4. Density

In still others, as **in quarrying**, a high density explosive is *sometimes used in the bottom of hole to ensure pulling the toe*, while a bulkier one is used *to obtain proper distribution of the charge*.

4. Density

A **useful guide in designing a blast** is to know approximately how many kilograms of explosive can be loaded in one meter of borehole. Because the density of water is 1.0 g/cm^3, products loaded into holes containing water must have a density greater than 1.0 g/cm^3 in order to sink.

4. Density

A useful expression of density is **loading density** (or **charge concentration**), which is the weight of explosive per unit length of charge at a specified diameter.

The **density** of an explosive determines the weight that can be loaded into a given column of borehole.

4. Density

The lineal **charge concentration** q_1 (kg/m) **in a blasthole** of diameter D and a density ρ_e, is calculated from:

$$q_1 = 7.854 \times 10^{-4} \times \rho_e \times D^2$$

where ρ_e = explosive density (g/cm^3), and D = charge diameter (mm).

4. Density

OR

$$de = 0.34 \times SG_e \times {D_e}^2$$

where:

de = loading density (lbs/ft)

SG_e = specific gravity of the explosive

D_e = diameter of explosive (in)

4. Density

EXERCISE

Determine the loading density of an explosive which has a charge diameter of 3 inches and a specific gravity of 1.2.

5. Detonation Pressure and Explosion Pressure

The **detonation pressure** of an explosive is a function of the density and of the square of the detonation velocity. It is measured when the detonation is propagated through the explosive column, as already indicated. The **detonation pressure** is generally considered as the pressure in the shock zone ahead of the reaction zone.

5. Detonation Pressure and Explosion Pressure

Although the **detonation pressure** of an explosive depends upon, apart from the density and the VOD, the ingredients of which it is composed, this parameter can be estimated from the following equation (Jimeno, C.L., et al. in *Drilling and Blasting of Rocks*, 1995):

$$PD = 432 \times 10^{-6} \times \rho_e \times \frac{VD^2}{1 + 0.8 \times \rho_e}$$

5. Detonation Pressure and Explosion Pressure

$$PD = 432 \times 10^{-6} \times \rho_e \times \frac{VD^2}{1 + 0.8 \times \rho_e}$$

where: PD = detonation pressure (MPa), ρ_e = density of explosive (g/cm^3), and VD = detonation velocity (m/s).

5. Detonation Pressure and Explosion Pressure

In the book of *Engineering Rock Blasting Operations* (Bhandari, 1997), the detonation pressure can be approximated as follows:

$$P = 2.5\rho \cdot V^2 \times 10^{-6}$$

where P = detonation pressure (kilobars), ρ = density (g/cm^3), V = detonation velocity (m/s).

5. Detonation Pressure and Explosion Pressure

The commercial explosives have a *PD* that varies between *500 and 1,500 MPa*.

Generally, in hard, very dense, and competent rocks the fragmentation is done more easily with high detonation pressure explosives, owing to the direct relationship that exists between this variable and the breakage mechanisms of the rock.

Detonation Pressure

Type	Detonation Pressure (kbar)
Granular Dynamite	20-70
Gelatin Dynamite	70-140
Cartridged Slurry	20-100
Bulk Slurry	20-100
Poured ANFO	7-45
Packaged ANFO	20-60
Heavy ANFO	20-90

5. Detonation Pressure and Explosion Pressure

The commercial explosives have a *PD* that varies between *500 and 1,500 MPa*.

Generally, in hard, very dense, and competent rocks the fragmentation is done more easily with high detonation pressure explosives, owing to the direct relationship that exists between this variable and the breakage mechanisms of the rock.

5. Detonation Pressure and Explosion Pressure

The *detonation pressure* is *different* from the **explosion pressure**, which is **the pressure after adiabatic expansion back to the original explosive volume.**

The **explosion pressure** is *theoretically* about **45%** of the detonation pressure.

6. Borehole Pressure

Borehole pressure is the theoretical pressure exerted on <u>the borehole walls</u> by the expanding gases of detonation after the chemical reaction has been completed, and before any expansion of the borehole wall has taken place.

6. Borehole Pressure

When an explosive charge is *initiated*, first a shock wave is caused, and then the pressure wave in the reaction zone follows (detonation wave).

In some publications, **borehole pressure** means the pressure at the wall of the blasthole, but in others the **borehole pressure** *has the same meaning as* detonation wave.

6. Borehole Pressure

Borehole pressure is a function of confinement and the quantity and temperature of the gases of detonation. **Borehole pressure** is generally considered to play the dominant role in breaking most rocks and in displacing all types of rocks encountered in blasting. **Borehole pressures** for commercial products range from less than 10 to 60 kbar or more.

6. Borehole Pressure

Some results for **borehole pressures** measured in both laboratory and field blasts can be seen in the book of *Rock Fracture and Blasting* (Zhang, 2016).

Many AN-FO mixtures have *borehole pressures larger* than their detonation pressures. In most high explosives the *detonation pressure is the greater*.

6. Borehole Pressure

In classical theory (ideal explosives), the **borehole pressure** is quoted as:

$$p_b = \frac{\rho_e {c_d}^2}{8} 10^{-6}$$ (ideal *fully coupled* explosives)

where p_b is the borehole pressure in MPa, ρ_e is the density of the explosive in kg/m³, and c_d is the detonation velocity of the explosive in m/s.

6. Borehole Pressure

- **coupling (explosive in blasthole)**: the degree and quality of interaction (filling) of the explosive charge with the borehole volume and borehole wall. It is defined by <u>the volume of explosive in relation to the total volume of the blasthole</u>

6. Borehole Pressure

- **decoupling**: normally a separation by air between the surface of an explosive charge and the blasthole wall where it is charged or sections of the blasthole left uncharged

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6. Borehole Pressure

The **borehole pressure** using *decoupled* charges can with reasonable reliability be calculated according to the following formula:

$$p_b = \frac{\rho_e {c_d}^2}{8}\left[\sqrt{R_a}\frac{d_e}{d_b}\right]^k 10^{-6}$$

(non-ideal and *decoupled* explosives)

6. Borehole Pressure

$$p_b = \frac{\rho_e {c_d}^2}{8}\left[\sqrt{R_a}\,\frac{d_e}{d_b}\right]^k 10^{-6}$$

where p_b = borehole pressure (MPa); ρ_e = density of the explosive (kg/m^3); c_d = velocity of detonation (m/s); R_a = axial *decoupling*, percentage of explosive column charged (%), d_e = diameter of the explosive after charging into the blasthole (m), k = a value which has to be determined experimentally on site (the value of k is ~2.6 according to Atlas Powder, 1987).

6. Borehole Pressure

- **axial decoupling**: the ratio between the length or volume of the blasthole being charged to the total available length or volume for charge in a blasthole

7. Stability

Explosives should be **chemically stable** and not decompose under normal atmospherical conditions. A method to check the stability is called the Abel test, which consists in heating a sample during a set time and at a specific temperature, observing the moment in which decomposition initiates. *For example*, nitroglycerine at 80° takes 20 minutes to decompose.

7. Stability

The **stability** of the explosives is one of the properties that is *related to* the maximum storage time of these substances, so that their effects in a blast will not be reduced.

8. Water Resistance

This is the capacity of an explosive product to withstand exposure to water without losing sensitivity or efficiency. Explosive products have two types of water resistance, *internal* and *external*.

Internal Water Resistance

Internal water resistance is defined as water resistance provided by the explosive composition itself. It varies with the composition of the explosive and is generally linked to the proportion of nitroglycerine or special additives that they contain; thus watergels, gelatin dynamites and emulsions are quite resistant to water.

External Water Resistance

External water resistance is provided not by the explosive materials itself, but by the packaging or cartridging into which the material is placed.

8. Water Resistance

The emission of reddish-brown or yellow fumes from a blast often *indicates* inefficient detonation reactions frequently caused by water deterioration of the explosive.

8. Water Resistance

Manufacturers can describe the water resistance of a product in two different ways. One way would be using terms of classification generally accepted goes from *Null* (has no resistance to water), *Limited, Fair, Good, Very Good*, to *Excellent* (guarantees a resistance of more than 12 hours).

Water Resistance

Type	Resistance
Granular Dynamite	Poor to good
Gelatin Dynamite	Good to excellent
Cartridged Slurry	Very good
Bulk Slurry	Very good
Air Emplaced ANFO	Poor
Poured ANFO	Poor
Packaged ANFO	Very good (becomes poor if package is broken)
Heavy ANFO	Poor to very good

Required Water Resistance in Different Blasting Operations

Blasting Operations	**Required Water Resistance**
Water is encountered in blasting operations	*At least* fair and should be detonated as soon as possible after loading
The explosive is to be in water for an appreciable amount of time	*At least* good
Severe (intense) water conditions and the exposure time is significant	Excellent

8. Water Resistance

Other way ratings would have been given numbers.

Classification	Prolonged exposure to water with no detrimental effects
Class 1	72 hours
Class 2	48 hours
Class 3	24 hours
Class 4	12 hours

8. Water Resistance

In general, **product price** is *related to* water resistance. The more water resistant the product, the higher the cost.

9. Sensitivity

This characteristic globally envolves various meanings that depend upon the type of external action that affects the explosive.

9. Sensitivity

- *Controlled action*: the sensitivity is equivalent to the acceptance of detonation by an initiator (e.g. electric blasting cap); **sensitiveness**
- *Uncontrolled action*: the sensitivity is a measure of the ease with which an explosive can be detonated by heat, friction, impact, or shock.

Cap Sensitivity (Sensitiveness)

Explosives should be sufficiently sensitive to detonation by an adequate initiator. This capacity varies depending upon the type of product.

As an example, the majority of gelatin explosives are initiated by *electric blasting caps*, whereas blasting agents generally require *a multiplier or primer of higher pressure and detonation velocity*.

Cap Sensitivity

One of the classifications used is the following:

Explosives that are *No. 8 cap sensitive*; and those that are not (*non cap sensitive*).

Sensitivity to Shock or Friction

Some explosives can detonate by means of subsonic stimulants such as shock or friction. For **safety purposes** it is important to know their degree of sensitivity when faced by these actions, especially during handling and transportation.

Shock resistance test

It is usually carried out with a *drop hammer (Kast)*, which consists in placing a sample of the product on an anvil, around 0.1 g, upon which a steel weight of 0.5 to 10 kg is dropped from different heights until explosion is achieved and a drop distance established.

Shock resistance test

For example, with a hammer of 2 kg, **mercury fulminate** detonates with a drop distance of 1 to 2 cm, **nitroglycerine** with 4 to 5 cm, **dynamite** with 15 to 30 cm, and **ammonical explosives** have drop distances of 40 to 50 cm.

Friction test

The most common is the *Julius Peter test*, in which an explosive is subjected to a friction process between two porcelain surfaces that have not been polished and upon which different pressures are exerted.

Friction test

After the test, any carbonization is noticeable as well as deflagration or explosion. The results are expressed in *kilos* which correspond to the pressure with which porcelain surface rubs upon the plate where the explosive is deposited.

Sensitivity to Heat

When explosives are heated gradually, they arrive at a temperature in which they suddenly decompose with release of gases, *increasing little by little* until finally a deflagration is produced or a small explosion. That temperature is called **Ignition Point**. In *black powder* it varies between 300 and 350°C, and in *industrial explosives* between 180 and 230 °C. This characteristic is different from sensitivity to fire, which *indicates inflammable properties*.

Critical Diameter

Cylindrical shaped explosive charges have diameters *below* which the detonation wave does not propagate or, if it does, it is with a velocity below the standard rate. This diameter is called **Critical Diameter**.

The principal factors that influence the critical diameter of an explosive are: particle size, the reactivity of its components, the density, and the confinement of said components.

9. Sensitivity

Type	Hazard Sensitivity	Performance Sensitivity
Granular Dynamite	Moderate to high	Excellent
Gelatin Dynamite	Moderate	Excellent
Cartridged Slurry	Low	Good to very good
Bulk Slurry	Low	Good to very good
Air Emplaced ANFO	Low	Poor to good*
Poured ANFO	Low	Poor to good*
Packaged ANFO	Low	Good to very good
Heavy ANFO	Low	Poor to good*

* Heavily dependent on field condition

10. Detonation Transmission

Sympathetic transmission is the phenomenon produced when a cartridge, upon detonation, induces the explosion of another that is adjacent.

10. Detonation Transmission

A good transmission within the blastholes is the guarantee that the explosive columns will be completely detonated. *However,* when those blastholes are close, or the charges within are decked, a sympathetic detonation can be produced by transmission of the strain wave through the rock, by the presence of underground water and structural discontinuities, or by pressure of the inert material of intermediate stemming upon the adjacent charges. In all these cases **the results of fragmentation and vibrations would be seriously damaged**.

10. Detonation Transmission

One of methods to measure the capacity or aptitude for sympathetic detonation, also defined as the *Coefficient of Autostimulation*, consists in calculating the maximum distance at which a primed cartridge can make another non-primed receiver cartridge explode, both being aligned with reference to their axis and well in contact with a ground or metal surface, or even inside tubes of different materials or in the open air.

10. Detonation Transmission

In the majority of the industrial explosives, the *maximum distances* at which <u>sympathetic detonation</u> is produced are between **2 and 8 times their diameter**, depending upon the type of explosive.

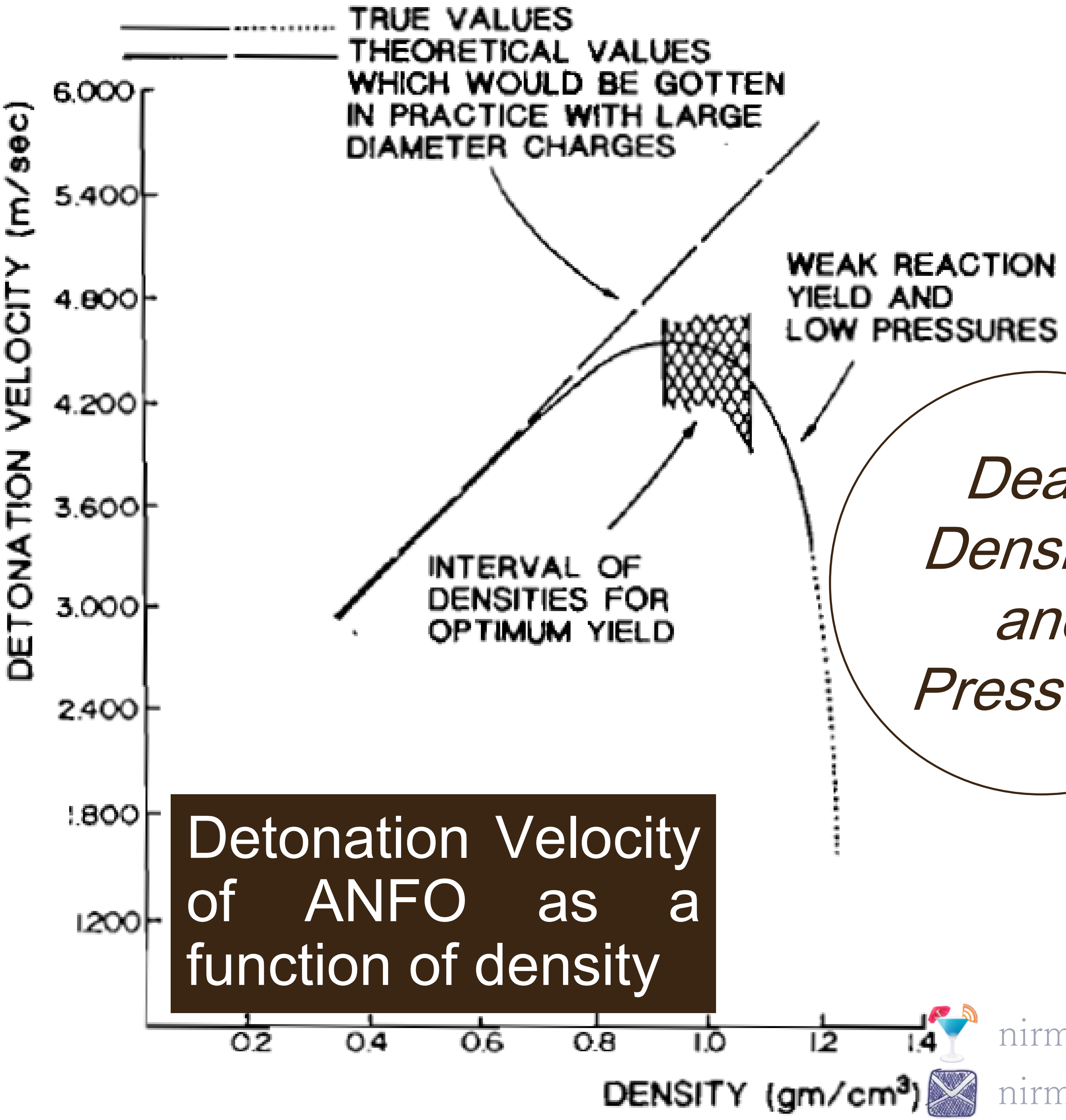
10. Detonation Transmission

The measures of the *Autostimulation Coefficient* can be taken either directly or indirectly; *however*, in the second, only 50% of the energy given by the direct method is transmitted.

The factors which modify the results of these tests are: aging, the calibre of the cartridges and the method used in testing.

11. Desensitization

In many industrial explosives it has been observed that the sensitivity diminishes when the *density increases beyond a certain value*. This phenomenon is *more acute* in those compositions or blasting agents that *do not contain* substances such as TNT or Nitroglycerine, etc.



Detonation Velocity of ANFO as a function of density

Death Densities and Pressures

12. Temperature Resistance

Explosive compounds can suffer (appear worse in quality) in performance if stored under extremely hot or cold conditions.

Under **hot storage conditions**, above 90°F, many compounds will slowly decompose or change properties and shelf life will be decreased.

12. Temperature Resistance

When the environmental temperature is **under 8°C**, the explosives which contain nitroglycerine tend to freeze. By adding a certain amount of nitroglycol, the freezing temperature is lowered to -20°C.

12. Temperature Resistance

Type	Between 0-100°F
Granular Dynamite	Good
Gelatin Dynamite	Good
Cartridged Slurry	Poor below 40°F
Bulk Slurry	Poor below 40°F
Air Emplaced ANFO	Poor above 90°F
Poured ANFO	Poor above 90°F
Packaged ANFO	Poor above 90°F
Heavy ANFO	Poor below 40°F

13. Fumes

The detonation of any commercial explosive produces steam, nitrogen, carbon dioxide, and eventually, solids and liquids.

Among the harmless gases mentioned, there is always a certain percentage of **toxic gases** such a *carbon monoxide* and *nitrogen oxides*. These resulting products are called **fumes**.

13. Fumes

If there is insufficient oxygen (a negative oxygen balance), the tendency to form **carbon monoxide** is increased. If there is an excess of oxygen (a positive oxygen balance), **oxides of nitrogen** are formed.

13. Fumes

The weight of paper and wax per cartridge affects oxygen balance and this must be considered in the calculation.

Because oxygen has such an important effect on the types of gases evolved, it is closely controlled in formulation. **Oxygen balance** is kept within specific limits to give the lowest practical content of toxic gases.

13. Fumes

- ✓ Poor product formulations
- ✓ Insufficient charge diameter
- ✓ Inadequate priming or initiation
- ✓ Water deterioration
- ✓ Lack of confinement
- ✓ The use of plastic borehole

13. Fumes

According to the proportion of harmful gases, a scale of classification has been established in degrees of toxicity for the operators after blasting.

Class	Volume of toxic gases (CO-NO_2) *dm^3 per 200 g of explosive*	Usage
1	0-4.53	Any type of UG work
2	4.53-9.34	Well ventilated areas
3	9.34-18.96	Surface blastings

13. Fumes

Maximum Allowable Concentrations (peak values) acceptable in general are:

- ✓ Carbon Monoxide, 50 ppm;
- ✓ Nitrogen Dioxide, 5 ppm.

13. Fumes

Type	Quality Relating Fume
Granular Dynamite	Poor to good
Gelatin Dynamite	Fair to very good
Cartridged Slurry	Good to very good
Bulk Slurry	Fair to very good
Air Emplaced ANFO	Good*
Poured ANFO	Good*
Packaged ANFO	Good to very good
Heavy ANFO	Good*

* Can be poor under adverse conditions

13. Fumes

There are several **ways to determine fume concentrations**. These include: measurements in the Bichel gauge, the Crawshaw-Jones Apparatus, the Ardeer Tank, field tests and theoretical calculations (Bhandari, 1997 in *Engineering Rock Blasting Operations*).

13. Fumes

The *most efficient* method is to take on-site measurements after the blast. A rather simplified approach is that of using spot samplers for detecting concentration of gases.

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