ROCK FRAGMENTATION

OBJECTIVES

At the end of this chapter, participants will be able to achieve:

- Fragmentation principles
- Factors controlling fragment size

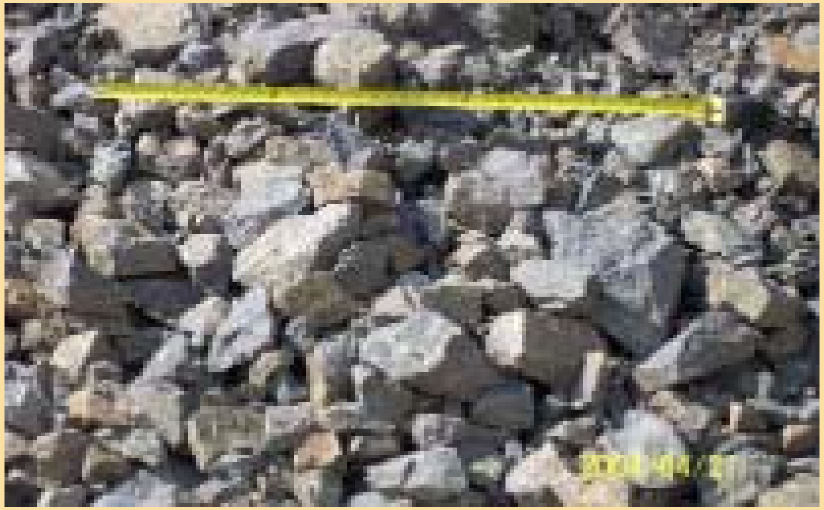
CONTENT

- Fragmentation Principles
- Factors Affecting Fragment Size
- How to Quantify the Fragmentation
- Calculation of Fragmentation
- Demands on Fragmentation
- Evaluation of Fragmentation

INTRODUCTION

When a round has been fired, the result is more or less always a subject of discussion. What then mainly is studied, at least in surface operations, is the fragmentation and the profile of the muck pile. This means, that the fragmentation together with the heave often are synonyms of the result

In most types of blasting, the fragmentation is the primary quality demand.



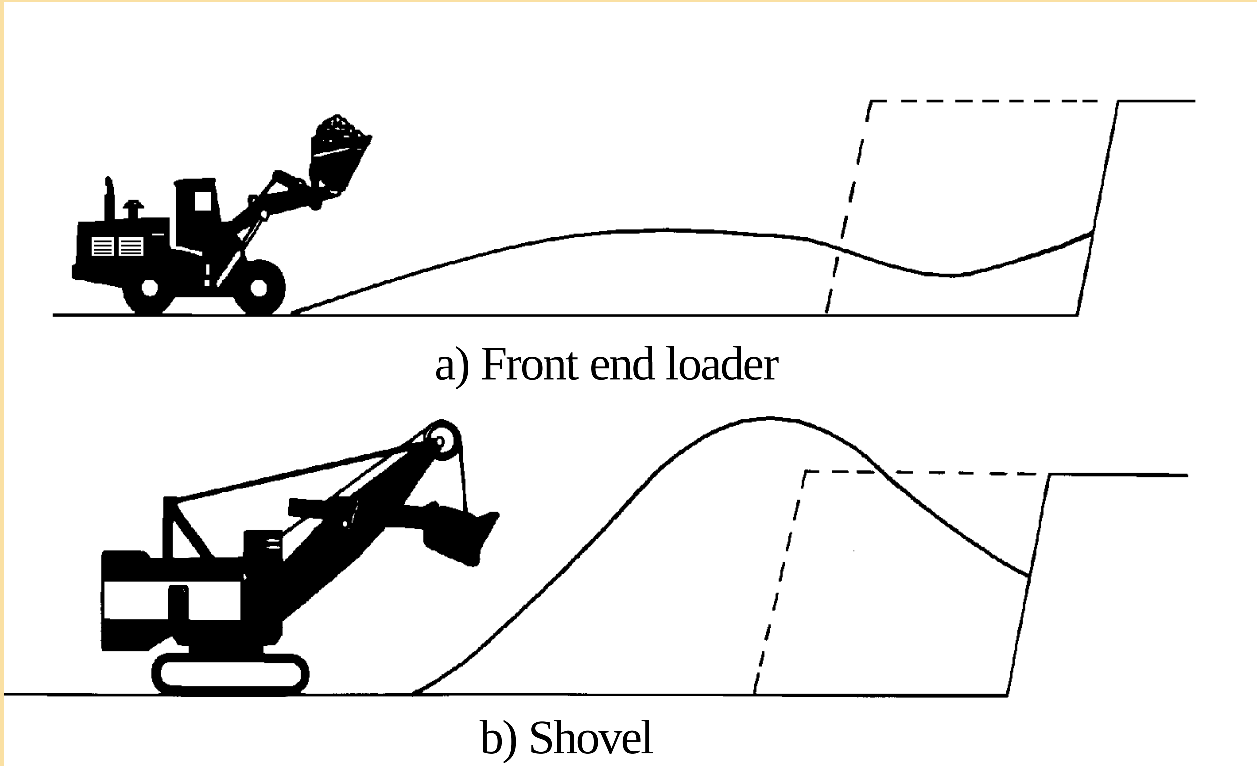
ROCK FRAGMENTATION

OPTIMUM FRAGMENTATION

- Minimise oversize boulders (less secondary breaking)
- Minimise ultra fines production
- Maximise Lump product
- Fragmentation enough to ensure efficient digging and loading
- Muck pile loose enough for fast cycle times and full buckets

OPTIMUM MUCKPILE SHAPE

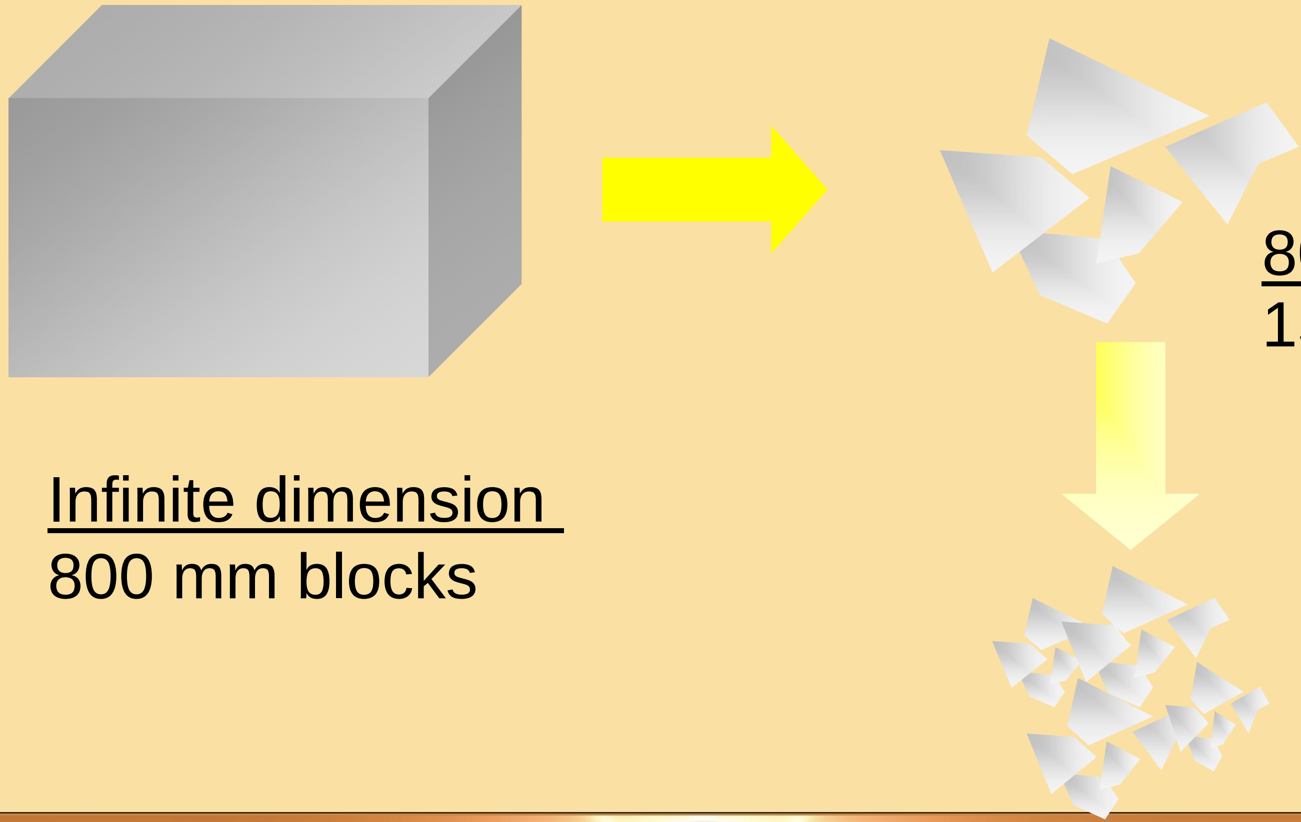
- Pit geometry
- Loading machines



FRAGMENTATION RATIO

Blasting

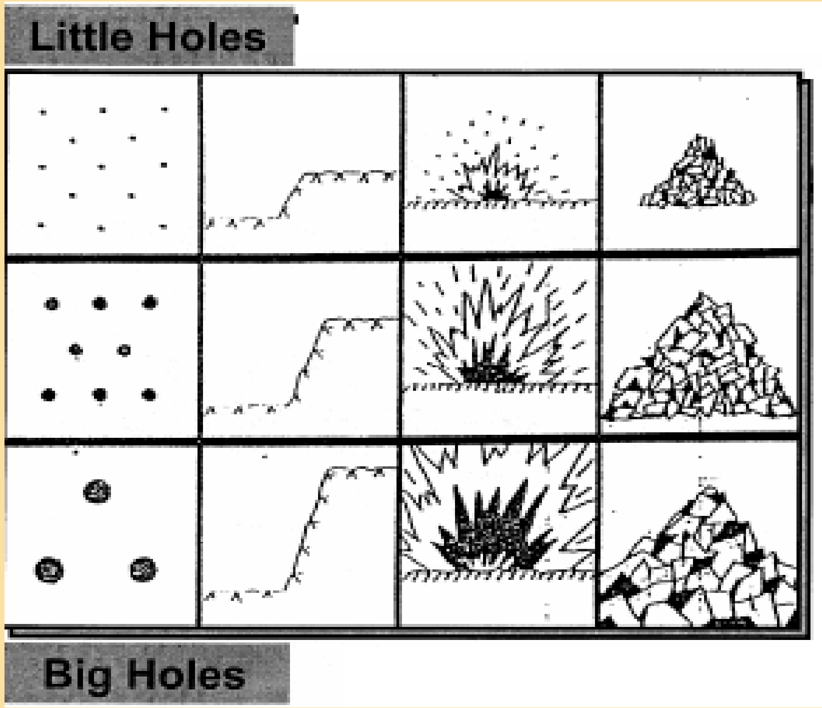
Crushing



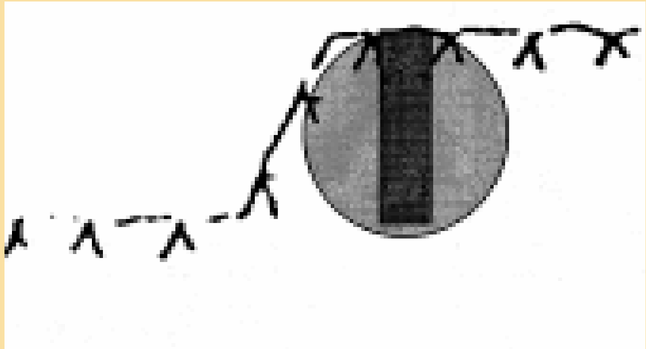
Infinite dimension / 800 mm blocks

800 mm blocks / 150 mm blocks

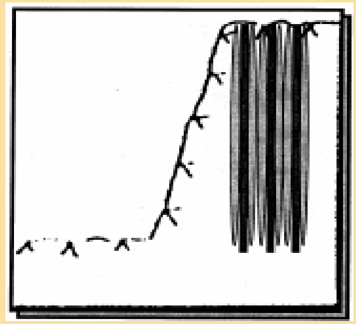
BENCH HEIGHT & HOLE DIAMETER



- Large hole diameter and small bench energy yield are difficult to control.
- Bad blast effect



- Small hole diameter and tall bench energy yield are reduced.
- Drill and blast cost is high



MINING CYCLE AND FRAGMENTATION

What do we mean by “a good fragmentation’?

To be able to answer this, let us first have a look at the complete working cycle to handle the rock, to see where the fragmentation may be important to the final result. This cycle is generally split up in following elements:

- Drilling
- Charging
- Blasting
- Loading
- Hauling
- Crushing and grinding

HOW TO QUANTIFY THE FRAGMENTATION

A commonly used method today to quantify fragmentation is to use the mean fragment size, often designated by k50.

- k50 is a figure which represents the screen size through which 50% of the loosened rock would pass if screened.
- This implies that a low value represents a fine fragmentation and vice versa.
- When a complete picture of the fragmentation is required, it is however necessary to know the entire distribution, i.e. the entire curve and not only one single point.
- Theoretically one and the same value of k50 could represent three completely different muck piles, for instance:
    - very fine and very coarse, with nothing in between
    - one fraction only, where the size corresponds to k50
    - the same amounts of all fractions from fine to coarse

HOW TO QUANTIFY THE FRAGMENTATION

Another way to quantify the fragmentation is by the oversize content.

- This could be expressed in percentage of the broken material exceeding an acceptable stone size.
- The acceptable stone size may be defined in different ways depending on actual conditions.
- One way is to relate it to the smallest side of the primary crusher, for example 75% of it.

HOW TO QUANTIFY THE FRAGMENTATION

The oversize content is a very good complement to the k50 value, as these two values together will provide a much better control of the fragmentation distribution than the k50 value alone.

CALCULATION OF FRAGMENTATION

Kuz-Ram Model

The Kuz-Ram model is probably the most widely used approach for the prediction of rock fragmentation by blasting. The unique feature of this model is that the input data consists of the relevant blast design parameters. Three key equations are the backbone of this model:

- **Kuznetsov's Equation:**
- **Rosin-Rammler equation:**
- **Uniformity index**

CALCULATION OF FRAGMENTATION

Formula was originally created by Kutznetzov and further developed by Cunningham:

$$X_m = A * K^{-0.8} * Q^{\frac{1}{6}} * \left[\frac{115}{RWS}\right]^{\frac{19}{20}}$$

Where

X_m	= mean particle size of muckpile, cm
A	= rock factor
K	= powder factor, kg explosive per m^3 of rock
Q	=mass of explosive in the hole, kg
RWS	= weight strength relative to ANFO

Rosin-Rammler equation:

$$Y_x = \exp\left[-0.693\left(\frac{x}{x_m}\right)^n\right]$$

Y_x	= mass fraction retained on screen opening, x
n	= Uniformity index

The n-value, which is dependent of drilling pattern, hole deviation, hole depth, charge length, etc, commonly varies between 0.8 and 1.5. A high value indicates uniform sizing, while a low value indicates higher proportions of both fines and coarse.

UNIFORMITY INDEX

$$n = \left[2.2 - \frac{14B}{d}\right]\sqrt{\left(\frac{1+\frac{S}{B}}{2}\right)}\left\{1 - \frac{W}{B}\right\}\left[abs\left\{\frac{CCL - BCL}{L}\right\} + 0.1\right]^{0.1}\frac{L}{H}$$

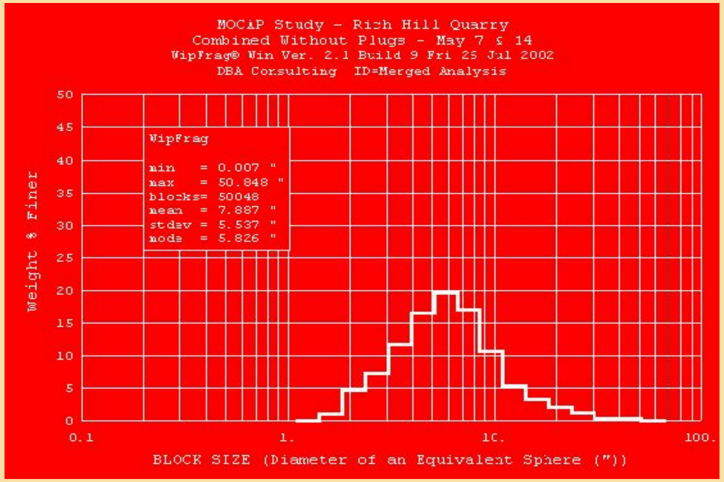
B = Burden, m;
S = Spacing, m;
d =hole diameter, mm
W = standard deviation of drilling precision, m;
L = Charge length, m
CCL = column charge length, m;
BCL = bottom charge length, m;
H = bench height, m

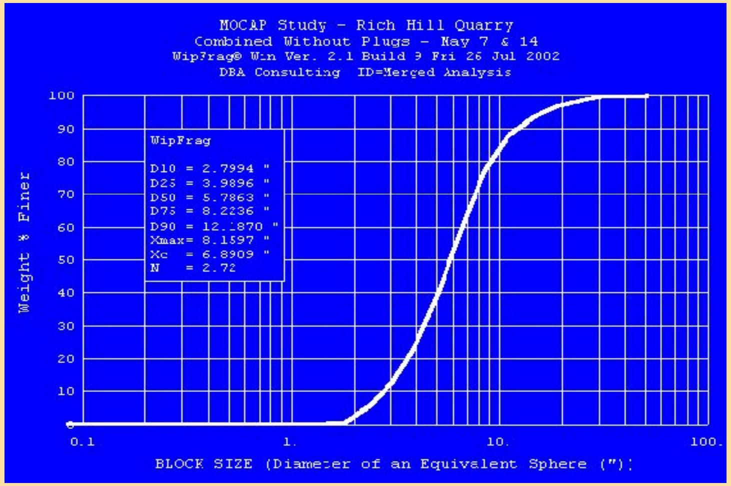
LIMITATIONS OF KUZ-RAM MODEL

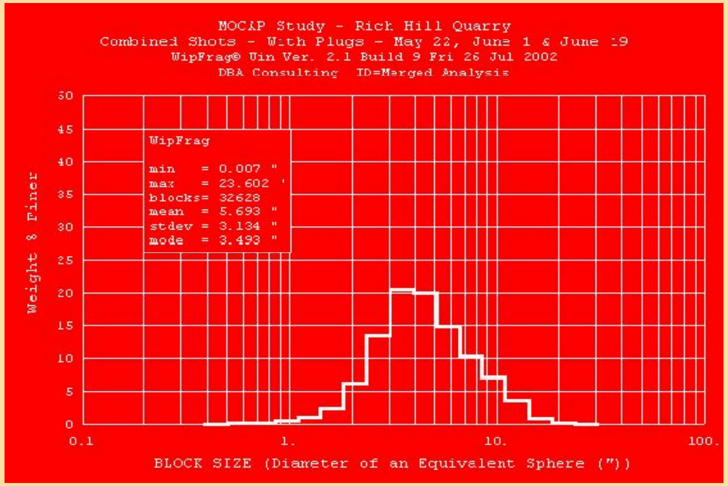
According to Cunnigham (2005), the Kuz-Ram model is a tool to examine how different parameters could influence the blast fragmentation and not a quantitative prediction model. The empirical models are based on the assumption that the fragmentation is generally proportional to the energy level of the explosive. This is valid in general but it does not take into consideration the following (Cunnigham, 2005):

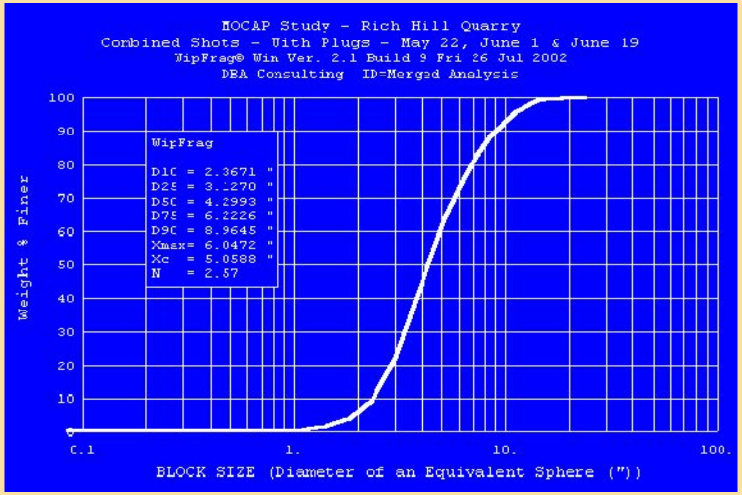
(i) Detonation behaviour of the explosive
(ii) Blast dimensions
(iii) Bench dimensions
(iv) Delays between holes
(v) Delay accuracy
(vi) Decking with air water and stemming
(vii) Edge effects

REPRESENTING FRAGMENTATION DATA









DEMANDS OF FRAGMENTATION

- If we look at an operation where the blasted rock is transported to a crusher, the fragmentation will primary have an influence on
    - Loading
    - Hauling
    - Crushing

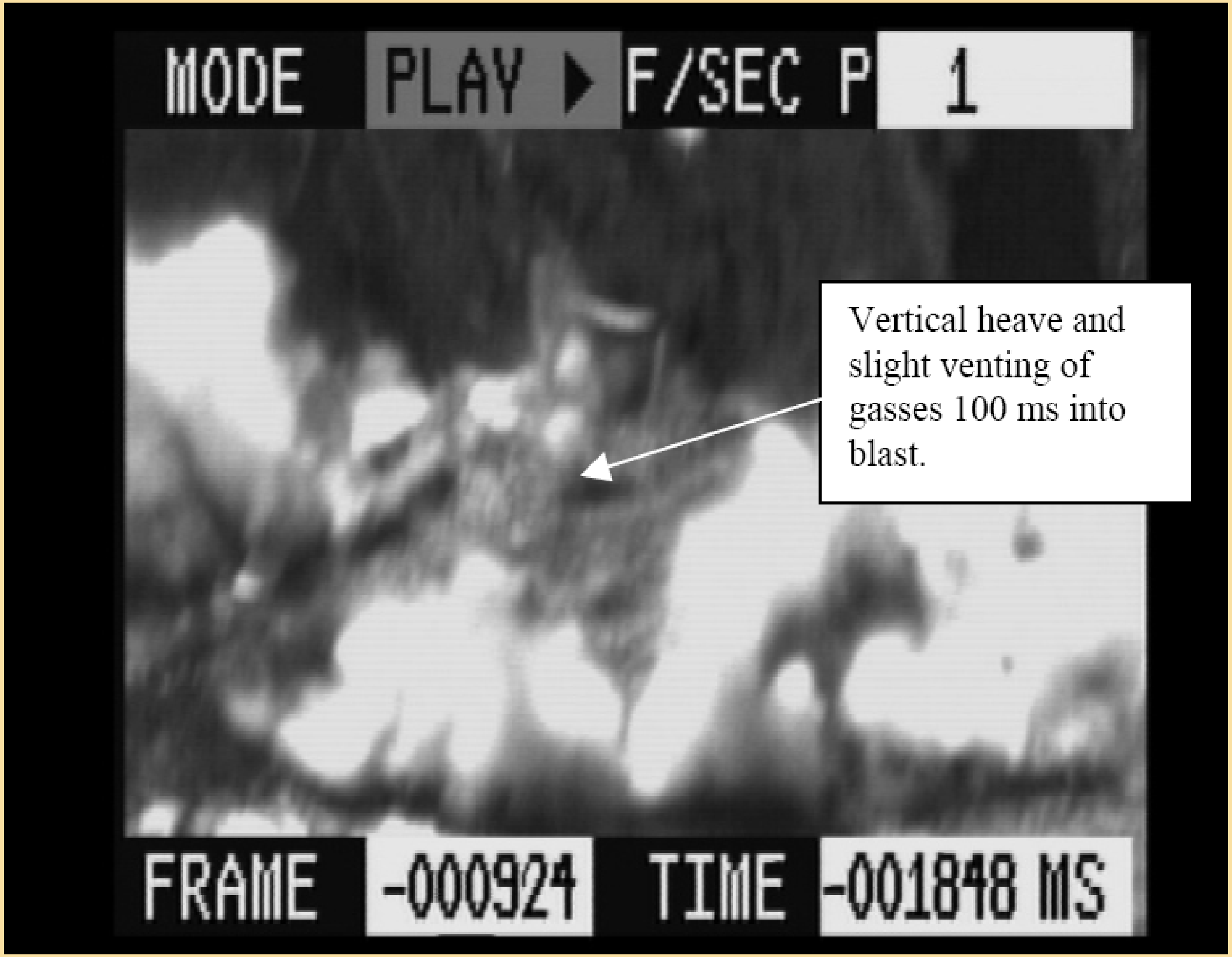
as regards production, wear and consequently also costs.

- To suit both loading and crushing, a favorable result from blasting would be a uniform material with a low mean size fragmentation.
- Too much fine and coarse material should be avoided.
- As can be seen, the demands may be different from one case to another. However, in general the total cost for the complete operation has to be optimized.

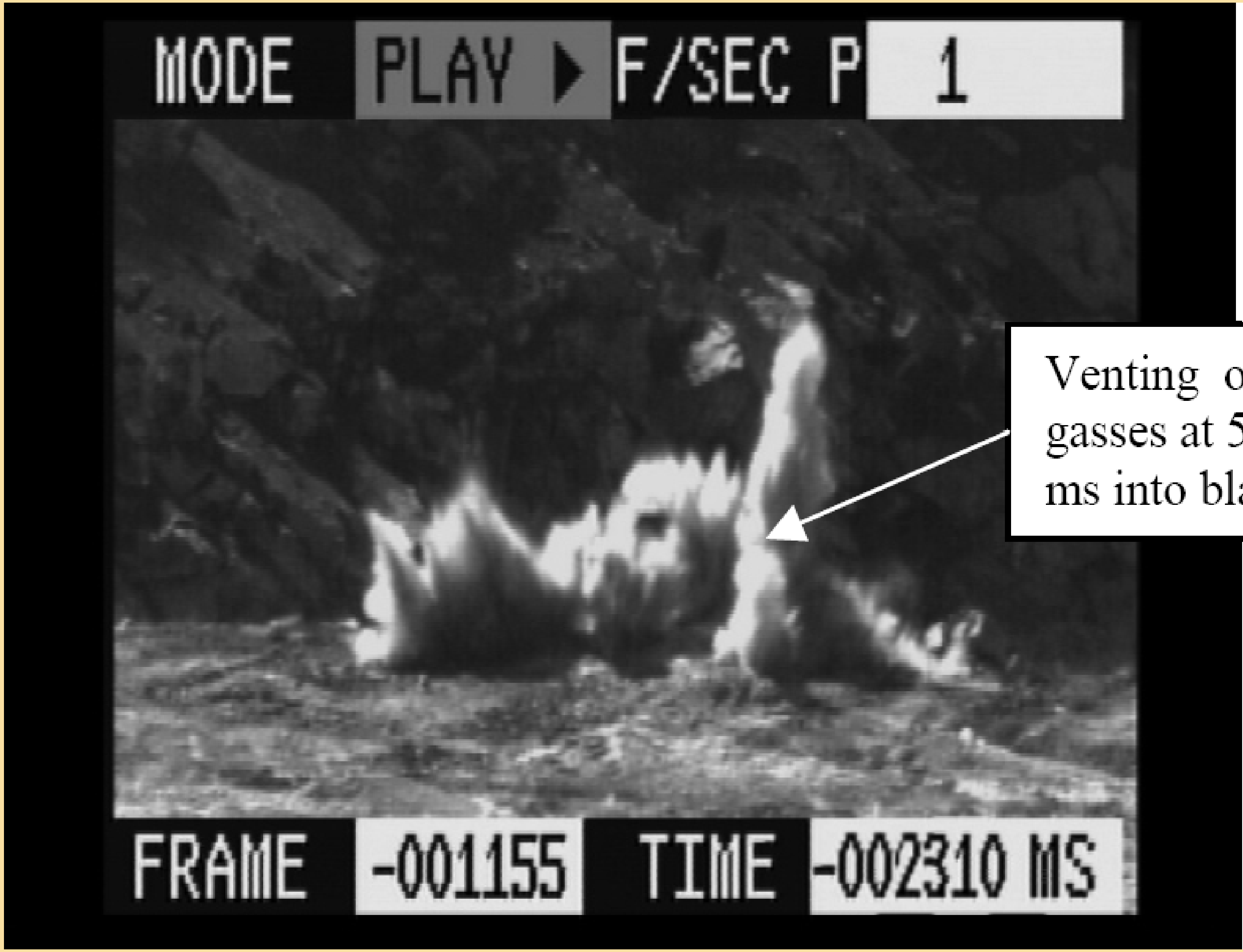
EVALUATION OF FRAGMENTATION

- Visual size assessment
- Loading production rate
- Digitizing of photos
- Comparison of photos
- Boulder count

BLAST MONITORING

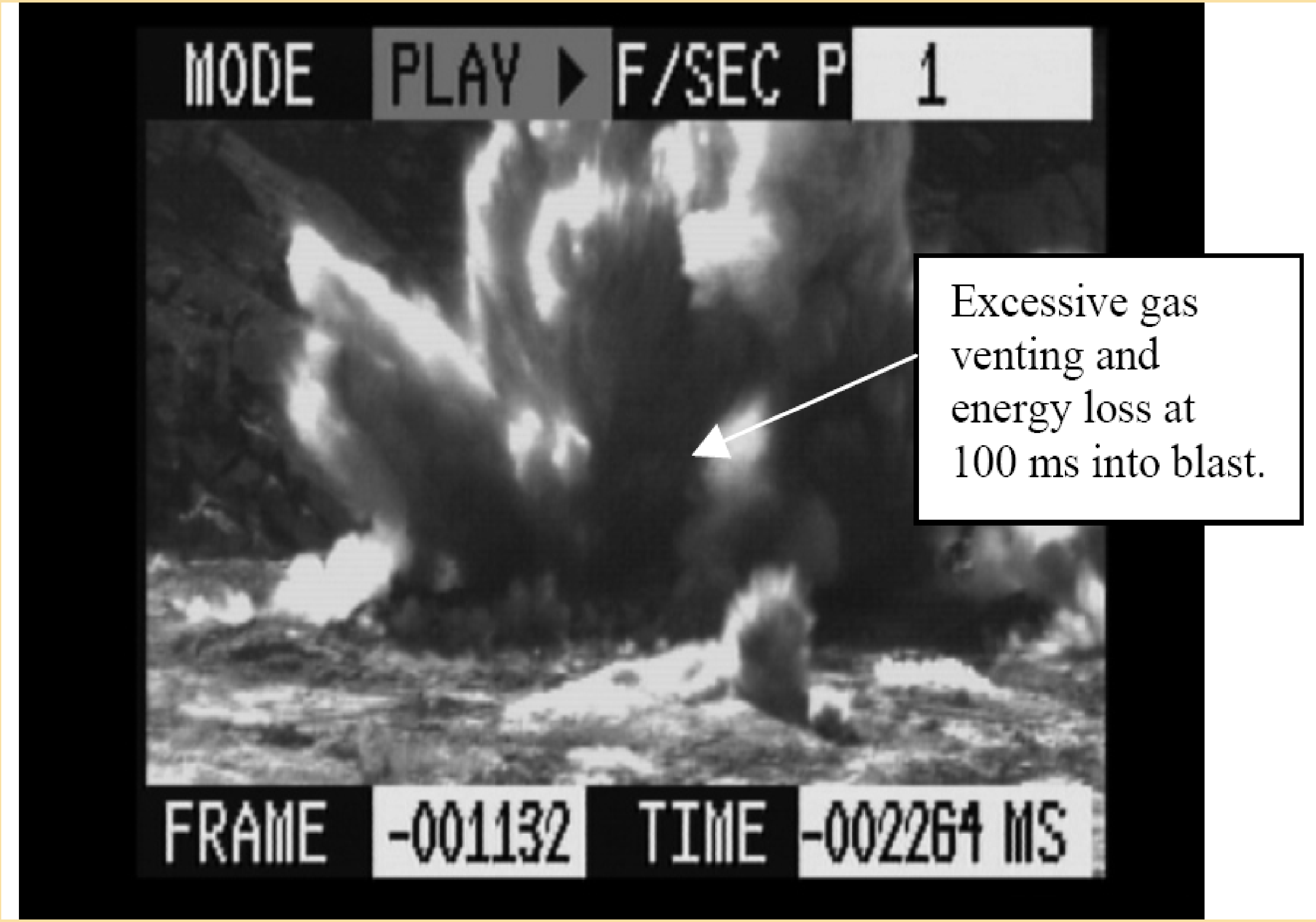


BLAST MONITORING



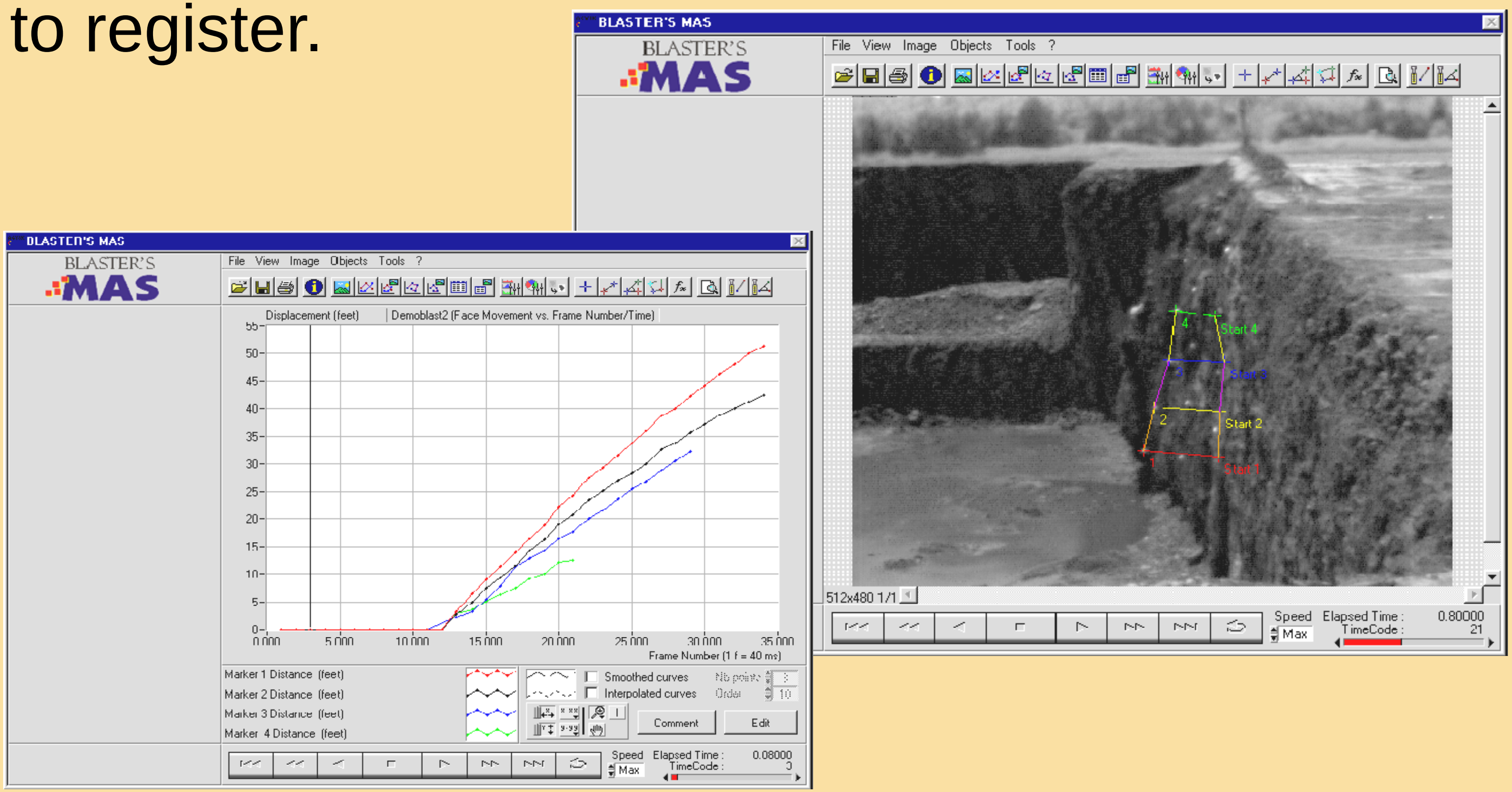
Venting of gasses at 54 ms into blast.

BLAST MONITORING



VISUAL SIZE ASSESSMENT

A very much used method due to its simplicity and low cost. Only large differences in fragmentation are, however, possible to register.



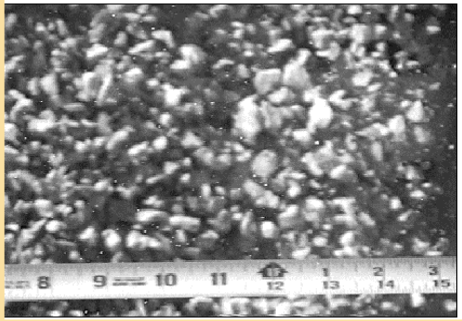
LOADING PRODUCTION RATE

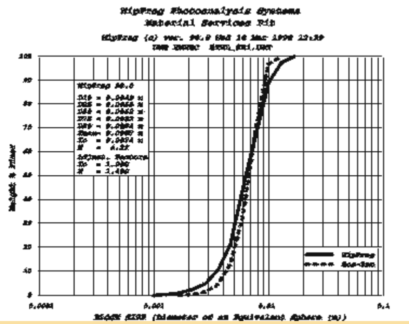
May be misleading if all factors are not taken into consideration. The production is for instance to very high degree affected by truck availability, skill of the operator, break- downs, etc.

Also when taking all these factors into consideration, it cannot be quite sure that the degree of fragmentation is reflected by the digging rate. For instance may an improvement to a finer fragmentation, but with an unfavorable distribution, cause worse digging conditions due to a tighter muck pile.

DIGITIZING OF PHOTOS

Means that photos are taken of the muck pile at different stages. Afterwards each single stone is digitized from the photos and transferred into a computer by means of a “pen’. The fragmentation distribution is then calculated by the computer.



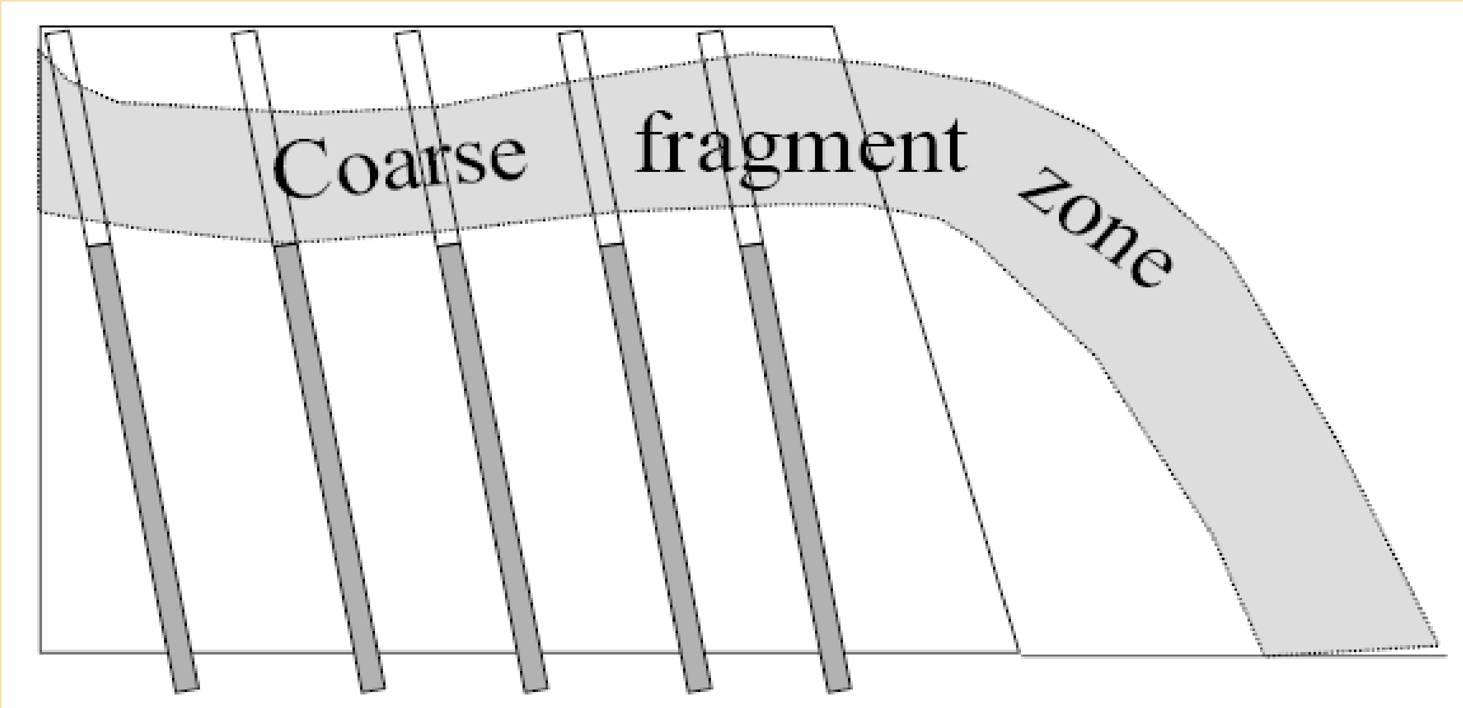


COMPARISION OF PHOTOS

- Also this method means that photos are taken of the muck pile at different stages.
- Each photo has to contain a scaling object, such as a ball of a known diameter.
- These photos are then compared to a set of photos, according to a certain system, where both the mean fragment size as well as the n-value are known.

BOULDER COUNT

This is a rather simple and common method where the number of boulders is a figure of the result. However, the method only takes oversize into consideration.



FACTORS INFLUENCING THE FRAGMENTATION

- The fragmentation is influenced by a number of factors.
- Some of them we know very well whereas others are more difficult to understand.
- The conditions of the rock are of great importance which means that the influence of changes of other factors can vary considerably from one place to another.
- A change of a parameter in one type of rock can for instance give an important difference of the result whereas a corresponding change in another place may not be noticed at all.

FACTORS INFLUENCING THE FRAGMENTATION

1. Rock conditions
The physical and mechanical characteristics of the rock as well as the structure are of great importance in rock blasting. Some of the properties normally discussed are:

Tensile strength of the rock
This is normally determined by the ‘Brazilian-test’ which is a more relevant value than the more common compression strength. According to Cunningham (3) rock with a tensile strength > 15 MPa should have a tendency to give a rough fragmentation whereas < 6 MPa is supposed to give a fine fragmentation.

Young’s modulus of the rock
For rock with the same tensile strength a coarser fragmentation is expected at a lower value of Young’s modulus than at a higher one. According to Rorke (8) this is most obvious when it is lower than 50 GPa.

The density and P-wave velocity of the rock
The product of the density of the rock and its P-wave velocity, is called the impedance of the rock, which according to some theories is of great importance.

FACTORS INFLUENCING THE FRAGMENTATION

2. Specific drilling and charging

The general rule is that an increase of specific drilling and specific charge gives a finer fragmentation.

This is also indicated in some way by the formulas used for calculation of the fragmentation.

To maintain a certain fragmentation it is therefore usual to increase the specific charge when increasing the hole diameter.

FACTORS INFLUENCING THE FRAGMENTATION

3. Drilling and firing pattern

- The placing of the holes is of importance for the blasting result.
- This applies to the location in relation to the structure of the rock and in relation to each other.
- The latter can be influenced by the relation between spacing and burden, E/V and how the holes are placed in a row in relation to the preceding row.
- A normally accepted rule of thumb says that for a constant area/hole, i.e. V*E = const. there will be a liner fragmentation when increasing the E/V and vice versa.
- By studying different tests the best fragmentation will be found at a staggered pattern.
- When a drilling and firing pattern is made it is important to study each hole at the moment of detonation.

FACTORS INFLUENCING THE FRAGMENTATION

4. Delay times

- The choice of delay times has a very big influence on the fragmentation, on one hand that the cracks shall have enough time to develop and on the other that the rock must get time to move to avoid problems for the rows behind.
- When choosing delay times the risks for throw and ground vibrations must be considered which in certain cases can give contradictory delay times.
- There are many different rules of thumb for the choice of delay times between the holes in a row as well as between the rows. Here are some examples:
- Delay between rows according to ‘Rock Blasting” : 3-5 ms/m burden.
- Delay between the holes in a row according to “Explosives and Blasting Procedures Manual” 3-15 ms/m burden.
- Between the rows it is recommended 2-3 times as big delay as between the holes.

FACTORS INFLUENCING THE FRAGMENTATION

5 Type of explosive

- In order to achieve optimal fragmentation an explosive adapted to the actual rock conditions should be chosen. With the knowledge today this is not easy.
- Even if there are certain general rules there are still many question marks. Among the properties of the explosive which may influence the fragmentation there are for instance:
    - Energy content
    - Gas volume
    - Detonation velocity
    - Density

- In order to get a satisfactory picture of an explosive's rock blasting performance it is necessary to take its environment into consideration because of the useful energy released by the explosive is dependent on a lot of factors, like
    - Properties of the explosive
    - Confinement of the explosive, i.e. properties of the rock
    - Hole diameter
    - Degree of coupling

CONCLUSIONS

Have to achieve:

- Fragmentation definition
- Fragmentation Measurements
- Factors affecting fragment size

Then we will have a good fragmentation, with no fly rocks, stable faces, low vibrations and regular floors.