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Izvorni znanstveni članak

CONTROL OF FRAGMENTATION BY BLASTING

Branko BOŽIĆ

Geotehnički fakultet Sveučilišta u Zagrebu, Hallera 7, HR-42000 Varaždin, Croatia

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The degree of fragmentation influences the economy of the excavation operations. Characteristics of blasted rock such as fragment size, volume and mass are fundamental variables effecting the economics of a mining operation and are in effect the basis for evaluating the quality of a blast.

The properties of fragmentation, such as size and shape, are very important information for the optimization of production. Three factors control the fragment size distribution: the rock structure, the quantity of explosive and its distribution within the rock mass.

Over the last decade there have been considerable advances in our ability to measure and analyze blasting performance. These can now be combined with the continuing growth in computing power to develop a more effective description of rock fragmentation for use by future blasting practitioners.

The paper describes a view of the fragmentation problem by blasting and the need for a new generation of engineering tools to guide the design and implementation of blasting operations.

Ključne riječi: Fragmentacija, Miniranje, Eksplozivi, Modeli za fragmentaciju, Proces fragmentacije, Eksploatacija

Stupanj fragmentacije odminirane mase ima utjecaj na ekonomsko poslovanje eksploatacije. Značajke odminirane mase kao veličina komada stijene, volumen i količina su osnovni čimbenici ekonomskih efekata rudarskih radova i osnova su razvoja kvalitete minerskih radova.

Svojstva odminirane stijenske mase kao oblik i veličina važni su elementi za postizanje optimalne proizvodnje. Tri su osnovna čimbenika koji direktno utječu na fragmentaciju odminirane mase: struktura stijenske mase, količina eksploziva i način aktiviranja minskih bušotina, odnosno rasprostiranje energije eksploziva u stijenskoj masi.

Koncem zadnjeg desetljeća zbio se znatan napredak u mjerenju i analizi minerskih značajki. U kombinaciji s razvojem i snagom računala omogućen je značajan razvoj opisa fragmentacije za buduće minerske radove.

U radu se opisuje i daje pregled problematike fragmentacije kod miniranja i primjene nove generacije inženjerskih pomagala za projektiranje minerskih operacija.

Introduction

The primary purpose of drilling and blasting is to fracture rocks and prepare the material for excavation and subsequent transport. The end purpose of rock blasting is to produce input material for a crusher. This is the case in most mining and construction rock blasting operations. Fragments produced by blasting should then not only be small enough for the loading equipment, but they should also be small enough to pass easily into the crusher opening.

Energy utilization and fragmentation process

The energy evolved on detonation of exsplosives is utilized in the fragmentation process by two groups of mechanisms.

First, stress wave of extremly short duration of the explosive; it is followed by quasistatic gas pressure generated by the gas product of explosion. A small zone of crushed rock is created immediately surrounding the hole, on detonation of explosive. Intensity of crushing and fracturing decreases as the distance from the hole walls increases till it reaches the transition zone beyond which other effects occur. The stress pulse propagates as cylindrical or spherical wave into the surrounding rock and induces besides the radial compressive stress, a circumferential tensile stress around the borehole. As this stress exceeds the tensile strenght of rock a pattern of radial fractures is created. As the stress wave travels outwards from the borehole, its amplitude is rapidly attenuated, so that after some distance no further crack initialization and eventually no crack propagation can occur. If however, this stress pulse reaches a free surface, it is reflected from there and its originally compressive radial component is reflected as tensile stress. This newly generated tensile stress may be of sufficient magnitude to exceed the tensile strenght of the rock, and this results in surface parallel scabbing or spalling of the rock. Multiple reflection of outgoing and reflected waves occur while fracturing takes place, dictating flaw initiation sites. As a result of quasistatic gas under high pressure acting in widened borehole and on the surfaces of the radial fractures, it causes further propagation of the cracks.

The gases also find their way into the stress induced radial fractures. In addition, flexural failure may occur at the surface, when the layers between cavity and free surface are bent outwards by the expanding gases.

The resulting rock fragments are finally pushed outwards and eject. During ejection process there is some consumption of energy in the collision of fragments and further fragmentation takes place. The exsplosive detonation also produces energy which does not in itself, load to fragmentation and does no useful work during blasting operations. This energy can be called as waste energy which finally yields accoustic energy, thermal energy in the fragmented mass and released gases, light energy and seismic energy. How much is the role of these mechanisms is not yet certain. This uncertainity is quite high, because roles of different mechanisms are affected with the changing blasting conditions.

In the practical blasting, conditions varied are: the blast parameters, rock parameters and explosive parameters.

Some important parameters which influence blasting results are known to be the burden spacing, orientation of joints in the rock.

Rock fragmentation

Rock formations as they occur are not homogeneous and isotropic and even on small scale the homogeneity varies (Božić & Braun, 1991). The structural control has a considerable influence on the geomechanical and dynamic properties of the rock formations.

The strength of rock mass decreases with the increase in frequency of joints and the deformability of rocks depend on their orientation.

It is the interaction between the rock mass and stresses generated due to explosive detonation which may produce favorable or harmful blasting results. Sometimes the joint planes add to the performance of explosive induced fragmentation mechanism (G a m a , 1977).

Blasting technology has advanced significantly over the last forty years.

The principal changes of relevance to the fragmentation of rock using explosives have been (S c o t t e t a l ., 1993) :

– The development of reliable bulk explosives. Blasting was revolutionized by the adoption of ANFO as bulk explosive. Pumpable water gel and emulsion explosives now provide a range of explosive properties and provide the blasting engineer with greater control over the type and distribution of explosive energy within the rock mass.

– The development of large diameter long hole drills. This technology allowed the design of long hole stopes containing large tonnages of ore per metre of development permitting significant economics of scale with regard to the cost of drilling and blasting.

– The development of flexible initiation system. Modern development system allow control over the initiation sequence of large number of holes with greater confidence than was possible in the past (G a m a & J i m e n o , 1993). Non-electric detonators with a precision of less than 3% are now readily available in most countries and electronic detonators which offer exceptional accuracy and wider selection of delay times are now being tested in full-scale mine blasts.

Blasting results are accessed according to the ability of the mining system to cope with the resulting muck. The effective cost of poor blasting can be several time the cost of the blast itself as can be demonstrated in terms of fragmentation alone.

Implications of poor fragmentation include:

– Increased secondary blasting. Secondary blasting of oversize is required to reduce it to a size that can be handled by the excavation machinery (P e r s s o n e t a l ., 1994).

– Reduced mucking rates. The rate of loading from a drawpoint is directly controlled by the size and looseness of the muck (B h a n d a r i , 1996). Extensive maneuvring is required by the excavator to load large rocks and bucket loads are usually reduced when working coarse muck.

Table 1. A list of engineering models

Model	Developer(s)	Purpose	Approach	Data Required
Blaspa 1963	Favreau	Detailed blast design and fragmentatin prediction	Dynamic model of crack growth	Detonic and physical rock properties and blast design
Kuz-Ram 1973	Kuznetzov	To predict average fragment size from bench blasting	Mean fragment size related empircally to blast design parameters	Powder factor, rock mass classification, explosive parameters
Sabrex 1973	Harries (ICI)	Fracture, heave, fragmentation and demage prediction	Crack patterns around blast holes generated by dynamic strain	Blast vibrations and dynamic rock properies
Blast Design Guidelines 1978	Langefors & Kihlstrom	Blast design guidelines	Formalising empirical blast design relationships	Rock breakage parameter, blast geometry and explosive description
JKMRC 1988	Kleine, Leung	Fragmentation prediction, explosive selection and blast design	Comminution theory applied to natural blocks within the rock mass	In situ blocks size distribution, energy distribution and breakage characterisation

– Difficulties in handling and transport. The efficiency of internal mine transport, crushing and transport from the mine can be adversely affected by poor fragmentation.

– Poor milling performance. The development and growing application of semiautogenous grindling mills and fully autogenous mills puts increasing emphasis on the size distribution of the ore delivered from the mine. Problems arise when the size distribution varies with time and when the proportion of fines exceeds desirable levels (W i n z e r e t a l ., 1983).

Fragmentation model

A focus on the underlying physics is the common thread that runs through the more mechanic models. They each model the interaction of cracks or fractures

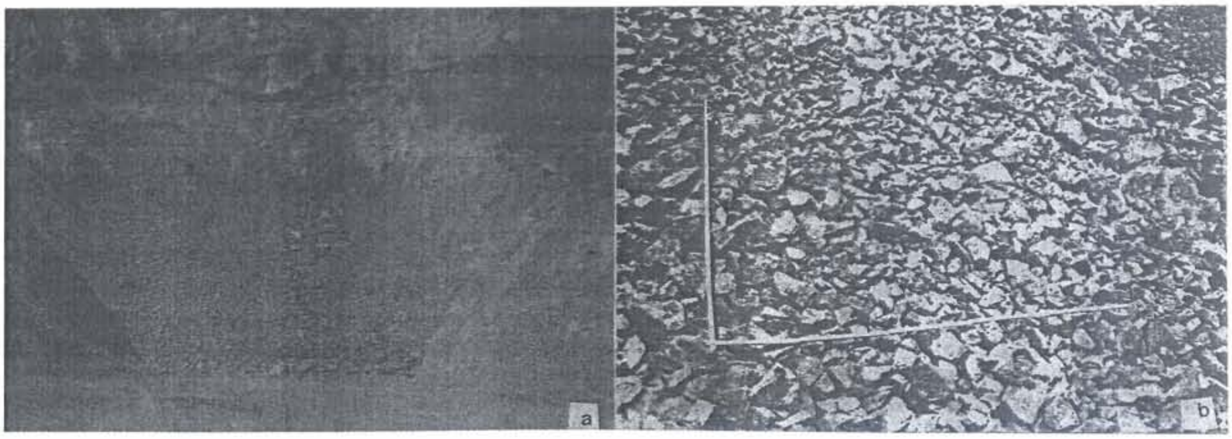

Fig. 1. a – fragmentation resulting from a blast
b – muck-pile at the Veličanka quarry

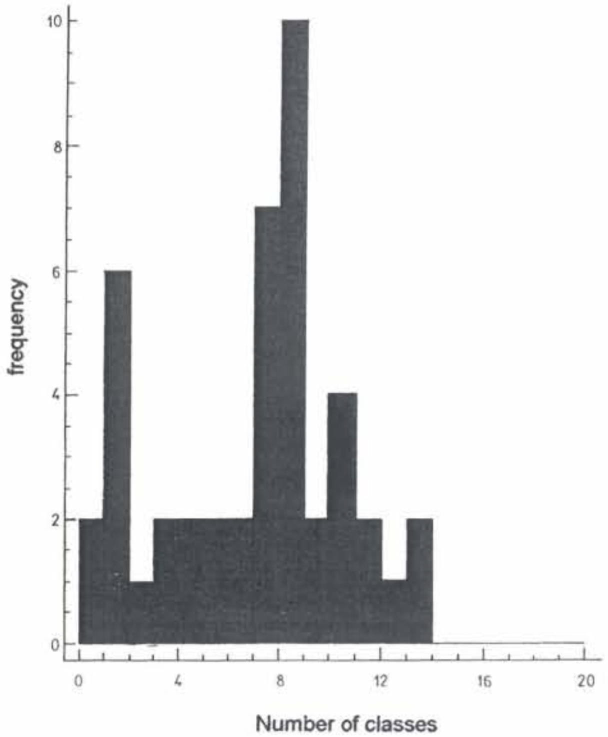

Fig. 2. Histogram of rock fragments after blasting along the x axis, the classrange is 1 cm

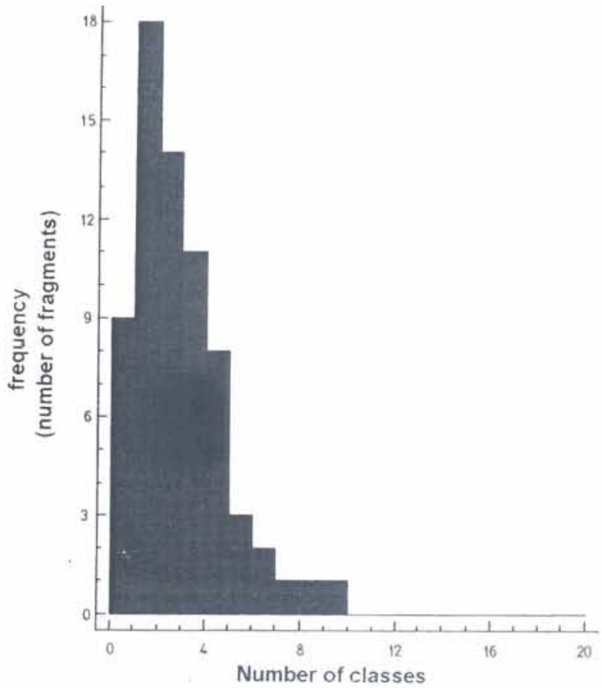

Fig. 3. Histogram of rock fragments after blasting along the y axis, the classrange is 1 cm

with stress waves and rely on a constitutive description of brittle fracture or crack propagation to calculate fragmentation (Wang et al., 1996). Their purpose ultimately is the investigation of fracture mechanics and not the development of an engineering tool, although some have been applied with great effort to actual blasts.

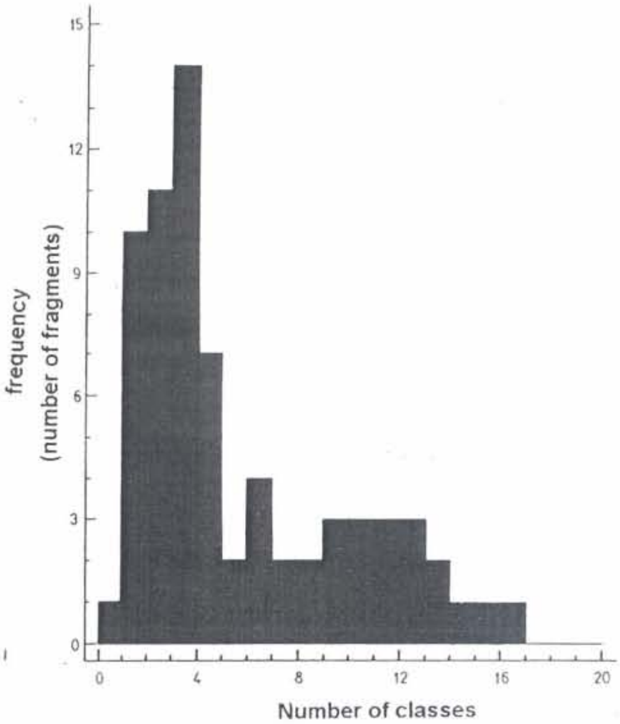

Fig. 4. Histogram of rock fragments after blasting along the z axis, the classrange is 1 cm

Table 1 shows summaries for same of the more well known models of fragmentation or rock breakage.

Many of the mechanistic models were never designed for engineering use.

By contrast the Kuz-Ram model has distinct advantages. Kuznetsov (1973) did research on fragmentation. His work relates a mean fragmentation size to the powder factor of TNT and to the geologic structure. Kuznetsov's work was very important, since it showed that there was a relationship between average fragmentation size and the amounth of explosive used in a particular rock type. With the use of the original Kuznetsov equation and modifications supplied by Cunningham (1983), you can determine the mean fragmentation size with any explosive and the index of uniformity.

With this information, a Rosin Rammler projection of size distribution can be made. Cunningham realized that the Rosin Rammler Curve had been generally recognized as a reasonable description of fragmentation for both, crushed or blasted rock.

Fragmentation analysis

Looking at the possible methods to evaluate the fragmentation a division into two basically different approaches can be made (Bhandari & Tanwar, 1993):

– direct measurement method
– screen analysis method.

Hand direct measurement method, it is possible to count the amount of boulders or to measure the pieces of rock directly.

Example 1. Dolomite Quarry Veličanka near Velika

Data obtained by a survey in the dolomite quarry Veličanka (Figs. 1 and 2) have been statistically analyzed by the computer program »Stratgraph«.

Fig. 5. Open pit Bukova Glava

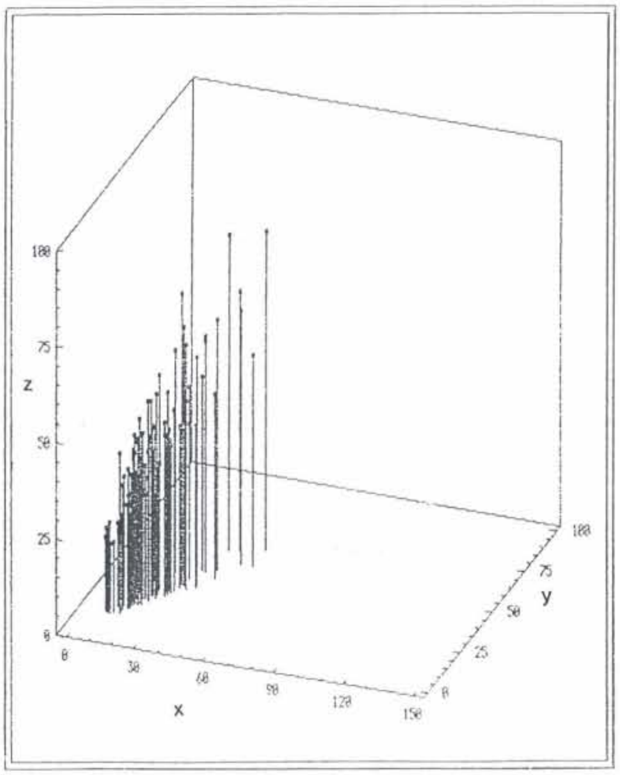

Fig. 6. Distribution of the fragment along the x, y and z axes in the 3D space, along the axes the clasranges are 1 cm

Distribution of rock fragments obtained after blasting is graphically illustrated by histograms. For every one surveyed area separate diagrams have been constructed with the intention to obtain a transparent information on the change of distribution of the fragments.

Heights of column bars are proportional to the numbers of fragments in a particular class.

Number of classes and their boundaries are displayed on the horizontal axis of the histograms.

It is possible to conclude from the diagrams (Figs. 3 and 4) that the fragments after blasting are quite unregular in size, as the histograms are quite wide and shallow. This means that there are large number of classes and a small number of fragments in each class.

Example 2. Open Pit Bukova Glava near Našice (Fig. 5)

Data obtained by measurements of after blasting fragments in the marl open pit Bukova Glava of the cement factory in Našice are interpreted by using the same computer program. Diagram (Fig. 6) is showing distribution of the fragments along the x, y and z axes in the 3D space (in cm) (Kleine et al., 1990).

Example 3. Dolomite Quarry Dolje near Zaprešić

Computer program »Precision Blasting Services« is able to interpret data in textual and graphical modes during design of the blasting parameters, as well as to forecast screening curves and the sizes of fragments after blasting (Božić & Marjanović, 1997).

Figure 7 is showing results of data analysis for the dolomite quarry Dolje near Zaprešić.

Other method is screen analysis. Single image measurements can be done either manually or automatically. In case of manual evalution the photo of the rock pile is digitalized using a standard CAD-software. Therefore a

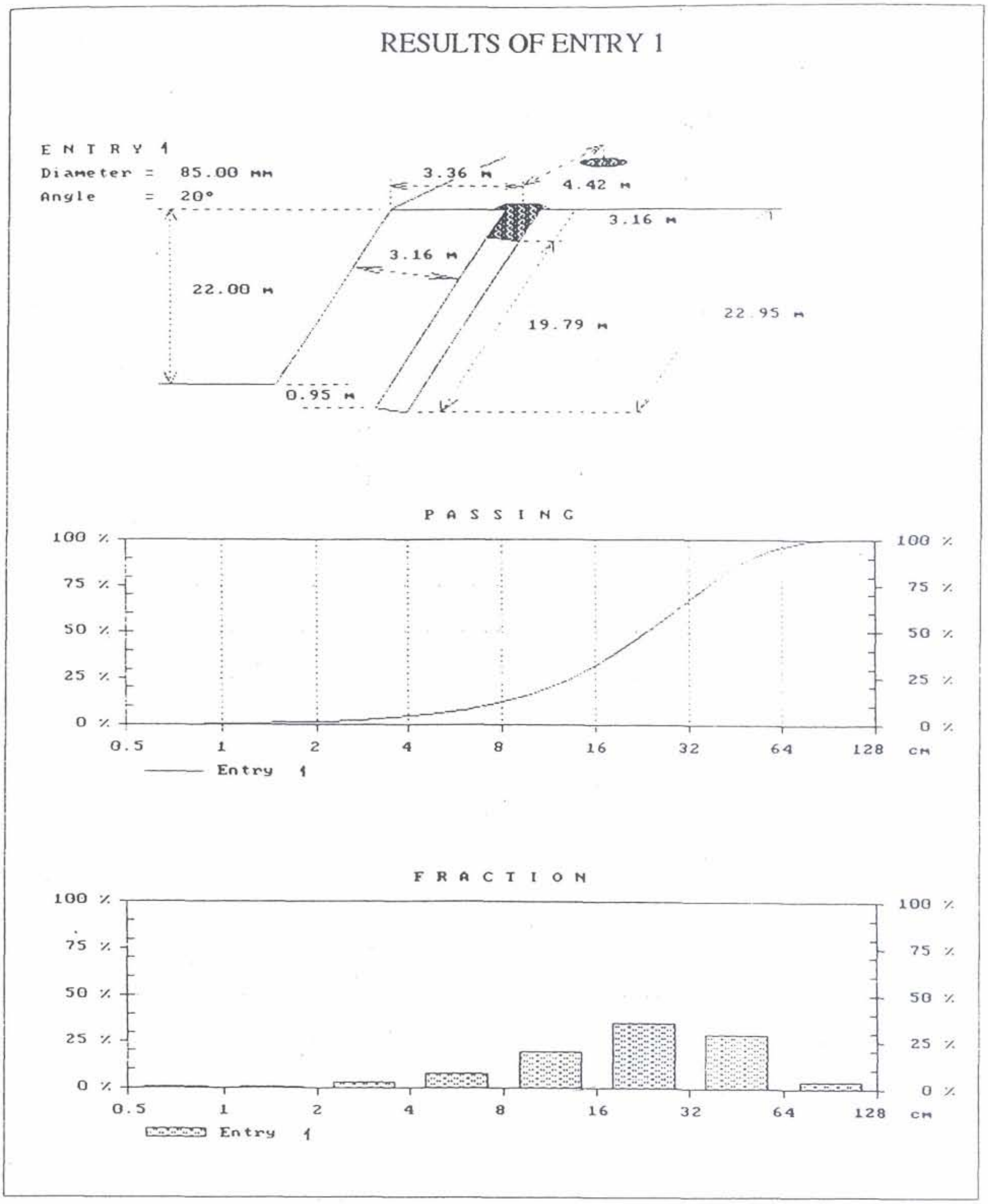

Fig. 7. Results of data analysis for the dolomite quarry Dolje

digitizer is required (Vogt et al., 1993). This work is very time consuming because the contour of every stone in the picture must be digitized for further calculations to determine the size of the rock fragments.

To illustrate the work with the image processing tool the following text describes some examples as it can be found in standard measurement application to determine the size distribution of blasted rock.

In this paper is not possible to explain the whole process, rather only an extract of the main staps and results can be shown here.

Figure 8 gives an overview about the work with the image processing tool.

The process starts with taking the photo of the muck pile in the quarry (Chiappetta & Borg, 1983). The photo then is digitized by a scanner. The scanner, which is the interface between image and digital information

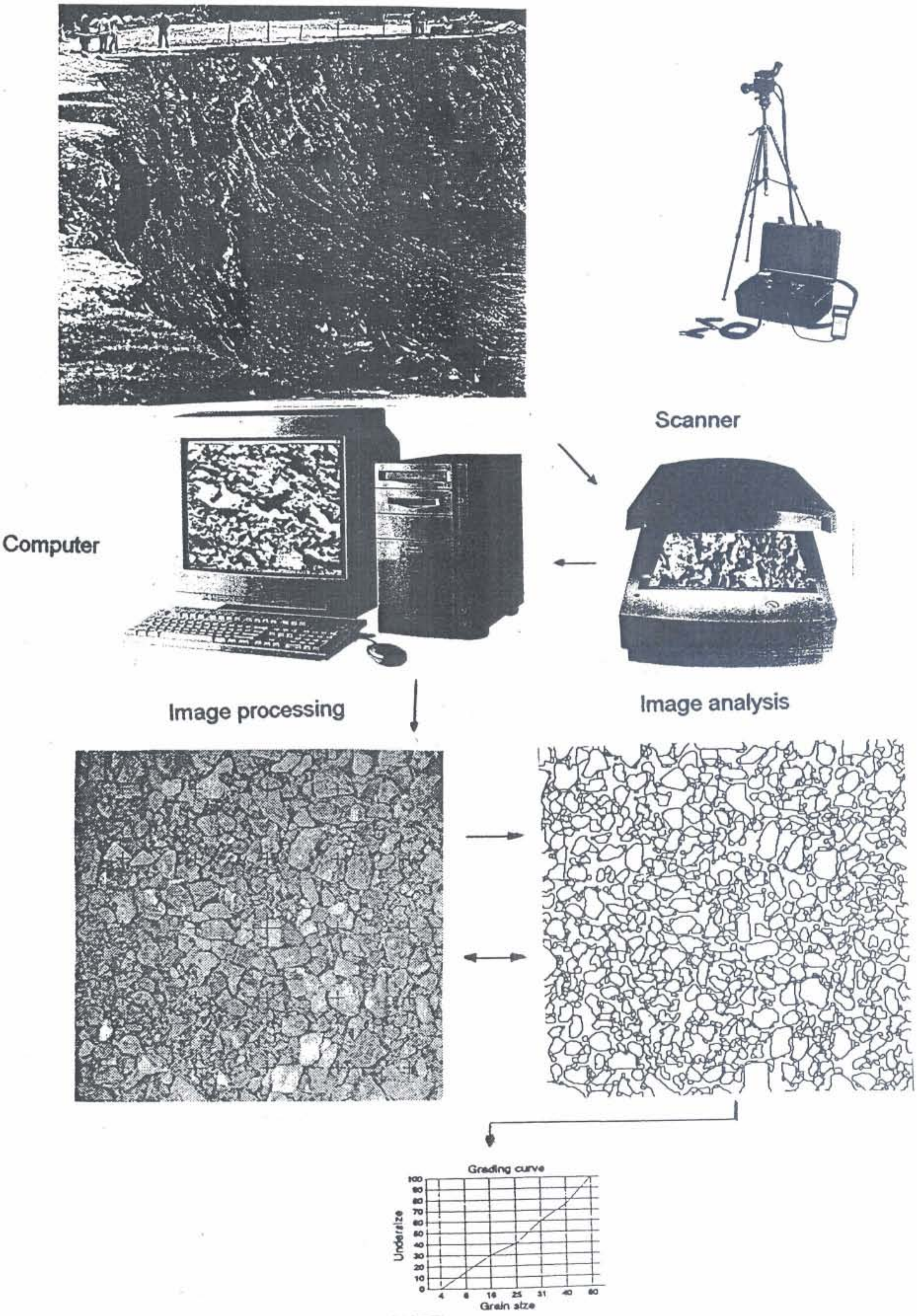

Fig. 8. Measurement process

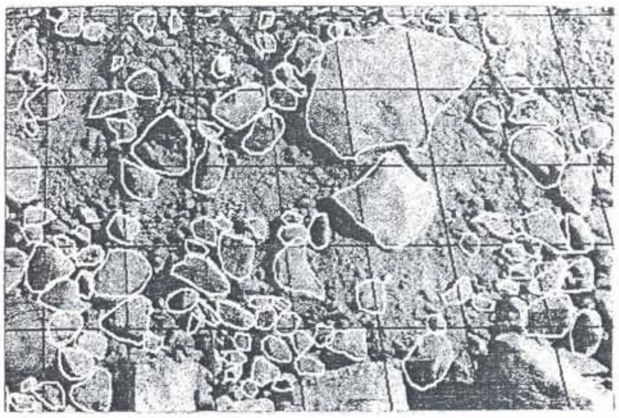

Fig 9. Input image for procesing

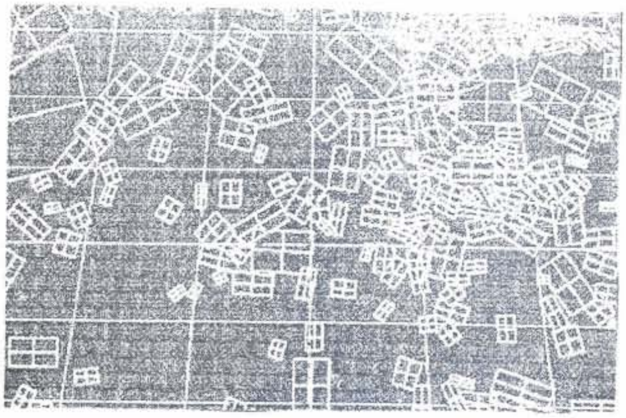

Fig. 10. Rentagular object contours

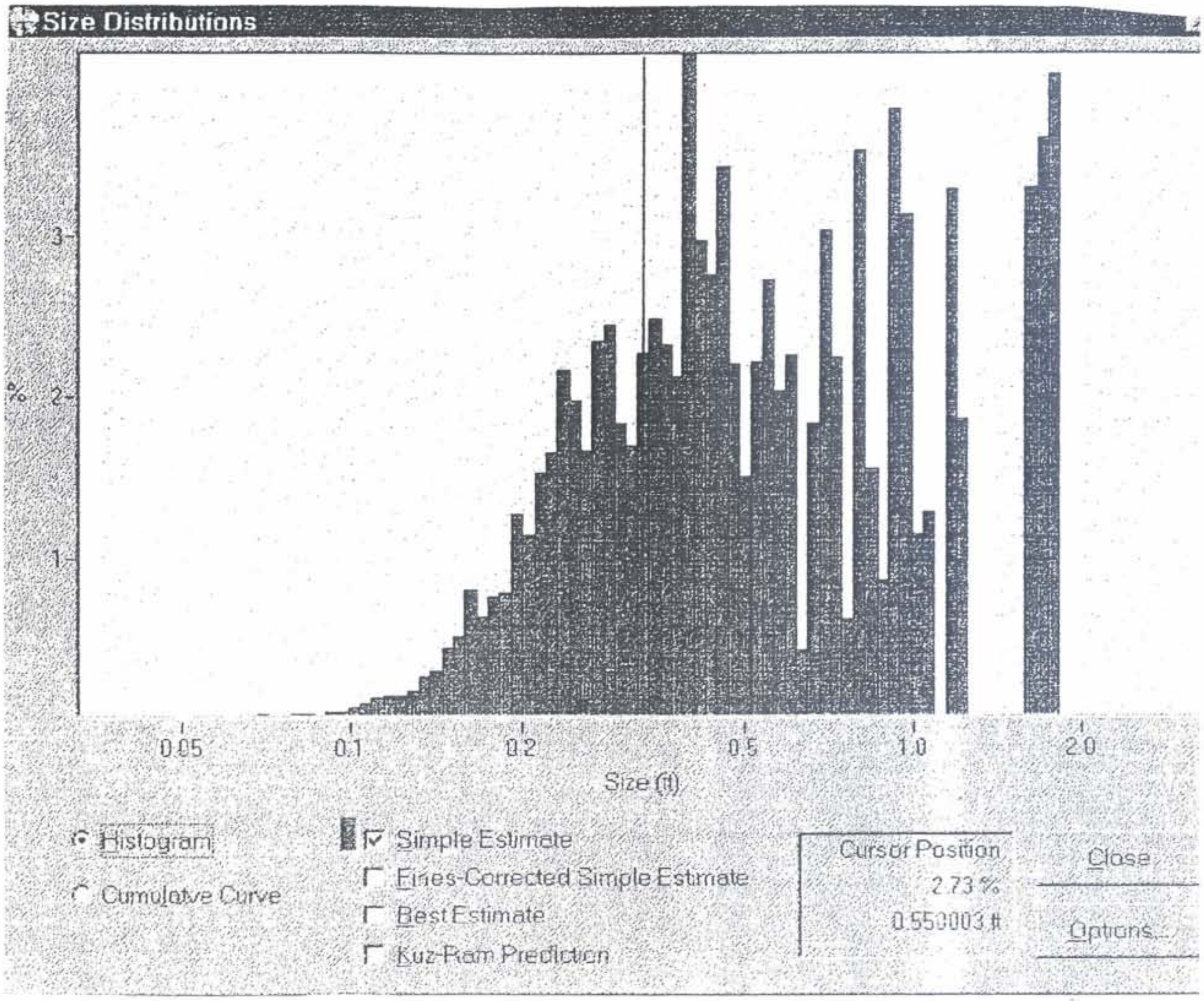

Fig. 11. Gold Size Histogram

required for computer calculations, screens the image into columns and rows. Each point of this matrix (pixel) is determined by its coordinates and its position on a grey scale.

Gold Size (Golder Associates, 1997) is a Windows based computer program to estimate the sizes of blast fragmentation size distributions. Rocks are traced manually using computer's mouse pointer (Fig. 9). With practice it is possible to digitize approximately 100 rock fragments in 10 minutes using a computer mouse. Program provides a true scale display of all particles in a sample, rather than their apparent size as shown in the sample's image. It also demonstrates the definition of particle size by finding and drawing the minimum bounding box around each scaled particle (Fig. 10). The width of the box is used to determine a particle's size, because this most closely relates to standard sieving.

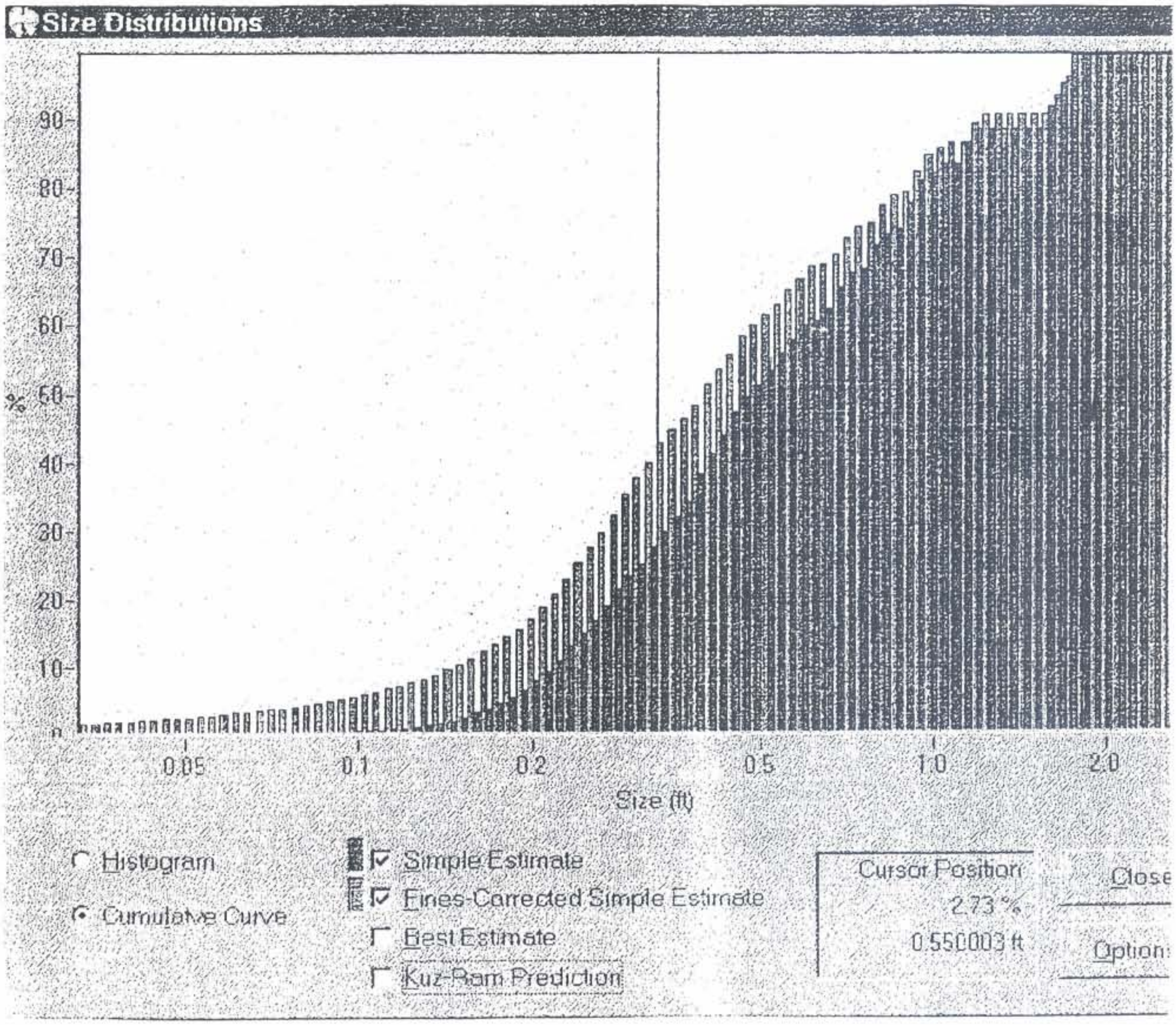

Fig. 12. Gold Size Cumulative Curve

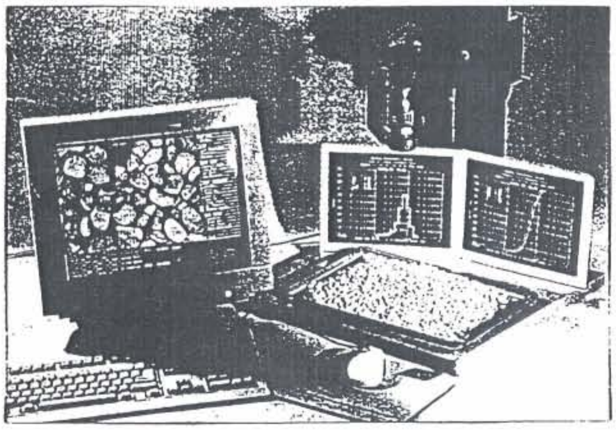

Fig. 13. Wip Frag program allows fully integrated automatic measurement

The results can be presented by:
- histogram
- cumulative curve

The histogram (Fig. 11) shows plots the actual content of the sizing, whereas the cumulative view (Fig. 12) is better to gain an understanding of the form of the distribution and to compare different distributions.

In the automatic measurement process a computer program identifies the stone contours.

Wip Frag I (Wip Ware, 1997) program is one of the important programs in blast fragmentation analysis (Fig. 13), Wip Frag II and III allows fully integrated automatic measurement and machinery control on moving conveyors and crushers in real time. No optimization program now a days can lead to reasonable results without including these informations to a minimum of effort.

Conclusion

The accurate control of fragmentation in rock blasting is justified by the advantages it provides, both in terms of economy and regarding its effect on the environment.

Analysis of many operations suggests that although mine blasts generally fragment rock so that it can be handled by the mining process, there is potential optimal fragmentation at the stoping face to improve the productivity and cost of all downstream processes.

Prediction of fragmentation has been the subject of much scientific and engineering research. Some empirical models have found practical application but there effectiveness has been limited by their simplicity.

During the last decade: effective blast monitoring tools, effective blast design tools, flexible initiation systems, rock mass mapping and modeling systems and fragmentation measurement systems, have been developed and can now be applied to the problem of both, estimating and achieving more controlled fragmentation. A possible path to better fragmentation modeling involves the probabilistic description of rock mass structure and dynamic analysis of the blast sequence to apply breakage models to the actual volumes of rock worked on by each blast hole at any instant of time.

The greatest potential technique is based on digital image analysis, which utilize specific hardware and software to quantifity bidimensional picture entities such as area, perimeter, shape, size and orientation.

Nowadays that processing include:

– Change of scale and correction of slope angles: using a reference sample within the mack pile and correcting its geometric distorsions

– Image acquisition: generally by means of video cameras and subsequent conversion to digital format

– Image magnification: with digital filters to obtain an enhanced picture of the fragments or by correcting illuminations problems

– Measurement: to evaluate block sizes by determining diameters of equivalent area circles, followed by their grading

– Stereometric interpretation: to establish the distribution of sizes with two dimension and transform those in three dimensions or volumes.

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