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Monitoring to evaluate blasting quality and the prediction of fragmentation

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SUMMARY

Rock fragmentation is considered the most important aspect of production blasting because of its direct effects on the costs of drilling and blasting and on the economics of the subsequent operations of loading, hauling and crushing. Over the past three decades, significant progress has been made in the development of new technologies for blasting applications. These include the advancement of modern instrumentation for monitoring, increasingly sophisticated computer models for blast design and blast performance prediction and more versatile explosives and initiation systems. The first problem one faces when dealing with rock fragmentation by blasting is how to define it. The size distribution of a blasted bench could be accurately defined by screening, but this is not practical as it would be far too expensive (laborious and interrupts the production) and time consuming. Therefore, numerous methods for the estimation of the size distribution of rock fragments have been developed. Because rock fragmentation depends on many variables such as rock properties, site geology, in situ fracturing, moisture content and blasting parameters, there is no complete theoretical solution for the prediction of blast size distribution. However, useful empirical models are used to estimate the size distribution. The most commonly used is the Kuz-Ram model, which is presented in the research report together with popular photoanalysis methods. Gold Size is a Windows based computer program to estimate the sizes of blast fragmentation size distributions. It can be concluded that by increasing the awareness and knowledge of the effects of rock fragmentation by blasting on the mining operations and the corresponding costs, the economics of an open pit can be improved.

The authors have developed a blast fragmentation model "SB" which will take into account the compressive/shear mechanism of blast fragmentation, and will be able to predict the entire fragment distribution curve more accurately, irrespective of the mechanical properties of the rock matrix.

Key words*: monitoring, blasting quality, rock fragmentation.*

1. INTRODUCTION

The productivity and the operating cost of pit or quarry equipment are affected by fragmentation and by muckpile loosening and profile. Crushing and grinding are directly affected by the fragmentation.

Throughput will be related to fragmentation mean size and the amount of plugging and bridging that occurs at the crusher.

Preconditioning can also affect grinding and crashing costs. Preconditioning is internal to the fragments we observe in the muck pile. It may be due to geology, especially in pits where there is much closely spaced, discontinuous jointing. Much preconditioning, however, appears related to micro-fracturing generated during blasting. Micro-fracturing may be related to energy input.

Given that primary blasting is generally the cheapest form of rock breakage and the downstream impact of unsuitable fragmentation is substantial, these savings will often disappear in increased costs in the pit and plant.

Costs deferred downstream are very likely to be considerably greater than the savings in blasting, so the overall cost of the operation will rise.

Therefore, fragmentation is an important issue. Obtaining the best cost of operation requires that fragmentation be appropriate to the site. This means looking at the effect on pit operations, but also beyond to the effects at the plant.

Fortunately, more tools are now available to predict and assess fragmentation. If used carefully and realistically, those tools can be quite helpful to blasters attempting to generate a fragmentation distribution most suitable to their operation.

2. ENERGY UTILIZATION AND FRAGMENTATION PROCESS

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

First, the stress wave of extremely short duration of the explosive; it is followed by a quasi-static gas pressure generated by the gas products of explosion. A small zone of crushed rock is created immediately surrounding the hole on detonation of the 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 strength of the 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 a tensile stress. This newly generated tensile stress may be of sufficient magnitude to exceed the tensile strength of the rock, and this results in surface parallel scabbing or spalling of the rock. Multiple reflection of outgoing and reflected waves occurs while fracturing takes place, dictating flaw initiation sites. As a result of quasi-static gas under high pressure acting in a 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 the cavity and free surface are bent outwards by the expanding gases.

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

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

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

3. BLAST MONITORING TO EVALUATE BLASTING QUALITY

In blasting there is always the question of how well the blast has performed relative to the results required by the quarry or mine operator. The assessment of blasting results generally considers such factors as:

- Fragmentation and the percentage of oversize,
- Muckpile profile,
- Occurrence of hard toe and undiggable areas,
- Backbreak and back throw,
- Flyrock,
- Vibration and airblast.

Over the years, these factors have been judged on more of a qualitative than quantitative basis. Therefore, assessment of blasting has been a less than perfect process in many cases.

More recently, an increasing number of tools have become available to the blaster for monitoring the results of blasts. Use of the various types of equipment, alone, or often in combination with one another, can allow considerably more informed and quantitative changes to be made in the blasting program. Available equipment includes the following types.

High-speed camera/video

High-speed cameras have been available for many years. In the last few years, high-speed video systems have been developed. Most provide black and white images but some color units are also available.

High-speed cameras or video allow one to see aspects of the blast that cannot be seen with the human eye. They allow quantitative analysis for face and top displacement, face velocities and millisecond delay detonation times, etc.

It should also be noted that much can be learned from the use of a conventional video camera. While the analysis is primarily qualitative some problems can be identified. Current day pricing on good video cameras is quite reasonable and there will be an advantage to the mine or quarry in using this equipment to film every blast. When the tapes indicate the possibility of problems, a high-speed camera or video study that provides quantitative results will often be a good investment.

Laser profilers

Laser survey equipment has been developed that does not require targets to take measurements. One use for this equipment is to profile the face in front of the blast. Overburdened or underburdened areas can be identified. Front row hole locations can be adjusted to give good breakage without undue air blast or flyrock. To profile the face a laser unit is set up in front of the face.

Numerous points on the face are measured from which a profile can be generated. If front row holes have been drilled the location of these can be picked up and plotted on the cross section as well. The location of maximum and minimum burden can be identified. In fact, these units can be used to quickly locate all the holes prior to blasting so that the blasting department has a clear picture of drilling accuracy.

Another important use for the laser equipment is muckpile profiling. It is difficult to obtain an accurate survey of the muckpile using conventional techniques because someone has to climb the blasted rock to provide target points. With the laser equipment this is not needed and many more points can be measured safely.

A better representation of the muckpile is obtained.

This is an important benefit when cast blasting is employed. It is important to be able to accurately measure the total and direct castover as a measure of casting efficiency and cost effectiveness. Even when casting is not used, muckpile profiles can be important for assessing whether blasting is providing blasted rock that can be most productive mined by the excavators in use.

Laser survey systems are therefore an important tool for both blast design and assessment.

Velocity of detonation (VOD) monitors

Reliable VOD systems for taking measurements in the field have been developed. These units allow one to examine how the explosive performs as used in the blasthole. Explosive quality problems, water attack and inadequate priming are examples of problems that can be identified using this equipment. The delay timing accuracy can also be determined. The amount of deck stemming needed to avoid cross propagation of independently delayed decks can be determined as well. In-hole VOD measurements can also help identify the effect of sleep time on explosive performance.

There are three types of VOD systems commercially available:

1. Time Domain Reflectometry (TDR) - This system was originally developed as the CORRTEX system. As used for VOD measurement it has similarities to sonar or radar equipment. A cable is placed in the hole. An electrical pulse is sent down the cable. When it reaches a discontinuity, such as the end of the cable, the pulse is reflected. As detonation proceeds up the hole, the cable is crushed. The time for the signal to return is progressively shorter. This can be converted to a velocity of detonation.
2. Continuous Resistance Wire Technique - This technique uses a probe wire of accurately known resistance. The choice and construction of the wire are quite important for obtaining good results. Upon detonation the wire is consumed. A constant current (or in some systems a constant voltage) is used to maintain a constant current across the probe wire, even though its length and, therefore, resistance are changing. Therefore, by Ohm's Law, the voltage must change directly with the resistance. Thus, the voltage will be proportional to the remaining probe length and the VOD can be calculated.
3. Fibre Optics System - This method will provide the average VOD between points a known distance apart. The fibre optics cables are placed in the blasthole at predetermined depths. When the explosive is initiated the detonation moves along the explosives column. When it reaches a fibre optics cable the light emitted travels along the cable. The light reaches an optical to electrical conversion unit that produces a voltage. When two or more cables are used the light travel over measured distances can be determined. Therefore, the average VOD over that distance can be calculated.

The continuous resistance wire and time domain reflectometry systems are the most commonly used commercial systems. They provide the most detailed information about the detonation.

4. THE PREDICTION OF FRAGMENTATION

Historically, it was difficult to predict what fragmentation would result from changes of explosive blast pattern, pattern layout, etc. Typically, changes were made and the results assessed qualitatively by inspection and by studying changes in equipment performance.

The ability to predict the fragmentation trend associated with changes in blast design became more quantitative with the publication of Kuznetsov's [2] work on calculating the mean diameter of fragments produced by blasting.

This empirical approach to fragmentation distribution became known as the Kuz-Ram Model. Several investigators subsequently worked on extending the model and making it more generally applicable.

Two papers by Cunningham [3] and [4] were particularly useful. The 1987 publication [4] extended the manner of calculating the influence of geology (the rock factor) and the effects of blast design (the uniformity index). The result of the original work by Kuznetsov and subsequent studies of other researchers meant that as the 1980s came to a close, Kuz-Ram was increasingly used to predict fragmentation.

Kuz-Ram model of blast fragmentation

The Kuz-Ram model combines two semiempirical formulas in order to predict fragment size distributions of blasted rock. A formula developed by Kuznetsov was used to predict the mean fragment size of the blasted rock, based on the use of TNT as the explosive. It was not until 1982 that Cunningham developed a more general formulation of the Kuznetsov equation suitable for other commercial explosives. Later, in 1987, Cunningham developed this model further to incorporate Lilly's concept, put forward the previous year, of the blastibility index as a measure of the suitability of rock to be fragmented by blasting.

According to the Kuz-Ram model, the mean fragment size can be calculated by:

$$X=A\cdot(V/Q)^{0,8}\cdot Q^{0,167}\cdot(E/115)^{-0,633} \qquad (1)$$

where:

- X - mean fragment size (cm),
- A - rock factor (an empirical constant determined from the rock density, strength and jointing),
- V - volume of the blasted rock (m^3),
- Q - mass of explosive per hole (kg),
- E - relative weight strength of explosive ($ANFO=100$).

An estimate of the fragment size distribution is given by the Rosin-Rammler equation, which is a negative exponential function, in the form:

$$R_{(x)}=1-e^{-\left(\frac{X}{X_c}\right)^n} \qquad (2)$$

where:

- R - proportion of the material passing screen of size X,
- X - screen size (cm),
- X_c - characteristic size (cm), (calculated from the mean size),
- n - index of uniformity.

The index of uniformity is determined by the blast design and bench height through the next equation, which includes the hole diameter, burden, spacing, charge length, drilling accuracy and bench height:

$$n=\left[2.2-\frac{14\cdot B}{d}\right]\cdot\left[1-\frac{W}{B}\right]\cdot\left[1+\frac{R}{2}\right]^{0.5}\cdot\left[\frac{L}{H}\right] \qquad (3)$$

where:

- d - charge diameter (mm),
- B - burden (m),
- W - standard deviation of drilling accuracy (m),
- R - spacing/burden ratio,
- H - bench height (m) ,
- L - charge length (m).

An increasing coefficient of uniformity indicates a more homogenised fragment size distribution reducing volumes of oversize and fines fractions. The values of uniformity coefficient usually vary between 0.8 and 2.0.

The fragment size distribution is presented as a Rosin-Rammler function of a form which is very similar to the equations describing the length of the intact blocks in the rock mass.

The probability of an intact length of rock being less than a specified size is given by:

$$F(x)=1-exp(-aX) \qquad (4)$$

where:

- a - mean fracture density,
- X - distance between cracks (m).

This equation indicates that the form of the Kuz-Ram fragmentation distribution curve is governed by the distribution of pre-existing fractures and discontinuities in the rock mass. The underlying mechanism of blast fragmentation, assumed within the Kuz-Ram model, is one of extension and coalescence of pre-existing fractures due to the tensile stress field generated away from the blasthole. However, this model does not take into account the mechanism of fragmentation caused by the compressive/shear failure of the rock matrix in the immediate vicinity of the blasthole. This is primarily the reason why the Kuz-Ram model, in its classical form, generally underestimates the proportion of fines (fragment sizes less than *10-20 mm*) generated during blasting. For relatively hard rock, this introduced error is insignificant as the actual zone of rock compression during a blast is relatively small (one blast hole diameter or less), so the Kuz-Ram model performs well. However, for softer rock, where the extent of the compressive zone around the blast hole is much greater, it becomes necessary to exercise caution when interpreting the results of fragmentation estimates and to develop separate models for fines prediction.

The actual volume of fines produced is governed by the interaction between the mechanical properties of the rock matrix (UCS, Young's modulus, density) and the properties of the explosive.

Fines are generated mainly close to the blasthole through the effect of the outgoing stress waves on the rock. This means that the form of the fines size distribution is not necessarily described mathematically by a negative exponential, but perhaps one that resembles the decay of the dynamic stress with distance, or one that correlates stress intensity with the spatial/temporal concentration of explosive energy or its derivatives.

5. FRAGMENTATION ANALYSIS

Another advance allowing people to consider fragmentation in more detail is computer-assisted fragmentation analysis.

The introduction of computer techniques using edge analysis allows more detailed study of fragmentation than visual inspection provides. Therefore, these methods have become important to quantitative analysis of fragmentation from blasting.

These techniques use photographs or video stills of the blast. The information is input to the computer through a video camera and capture board and the analysis performed.

The fragmentation must also be measured at various times during excavation of the blast to determine the distribution of fragmentation throughout the bank.

Using these techniques will be quite helpful in avoiding problems associated with the ability to distinguish various size fractions.

Looking at the possible methods to evaluate the active fragmentation a division into two basically different approaches can be made:
- direct measurement method,
- screen analysis method.

5.1 Direct measurement method

By using the 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 Ivanec near Zaprešiæ

Moreover, slope stability and successful blasting are affected by rock fracturing degree. Simple measuring of the sizes of rock fragments divided by natural discontinuities in all three characteristic directions (normal to layers, axial plane of fold areas, and its structural axis "*b*") and subsequent statistics of measured values may be used for the determination of the grain size distribution in blasted rock.

These statistical results show that the populations are log-normally distributed. Estimations of the grain size distribution can be made on the basis of a diagram of cumulative frequency drawn on probability paper.

The probability of getting certain particle sizes in blasted material can easily be read out from that paper considering the natural tectonic fabric [5].

Based on these diagrams we conclude that the grain size distribution of the blasted material has following characteristics (Table 1):

Table 1 Grain size distribution of blasted material

Grain size Measurement	*Normal to bedding*	*Normal to axial plane*	*Normal to struct. Axis "b"*
Average	*22,3 mm*	*18,3 mm*	*19,3 mm*
0-4 mm	*1 %*	*3 %*	*3 %*
4-8 mm	*14 %*	*32 %*	*8 %*
8-6 mm	*25 %*	*11 %*	*32 %*
16-32 mm	*30 %*	*33 %*	*37 %*
>32 mm	*30 %*	*21 %*	*20 %*
Rock blocks over 27×18×16 mm - 0,1 %			

Figure 1 shows diagrams of cumulative frequency of measuring rock particle sizes (discontinuity density), naturally dislocated by discontinuities, carried out normally to the sediments, normally to axial plane cleavage and the discontinuities parallel to it, and *a* direction normal to the regional structural axis *b*.

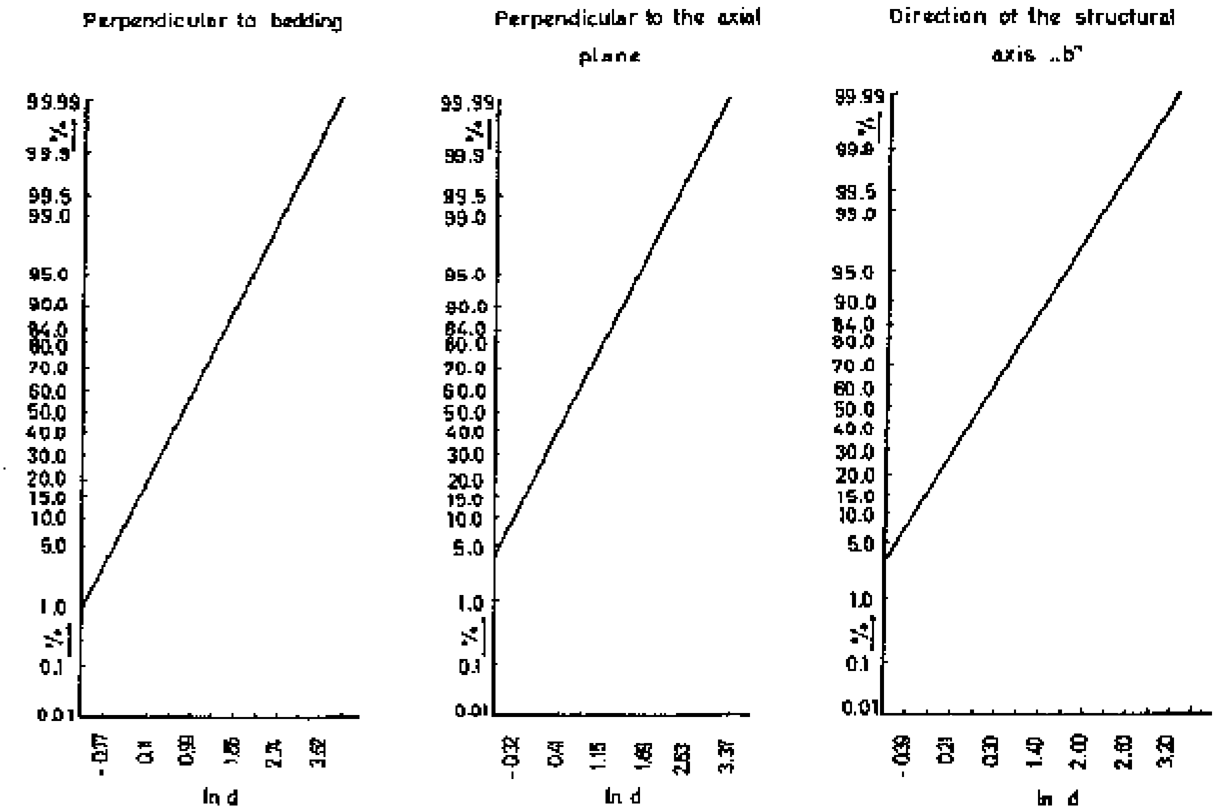

Fig. 1 Diagrams of cumulative frequency of measuring rock particle sizes

Example 2. Dolomite Quarry Velièanka near Velika

Data obtained by a survey in the dolomite quarry Velièanka (Figure 2) have been statistically analyzed by the computer program “Stratgraph”.

Distribution of rock fragments obtained after blasting is graphically illustrated by histograms. For every surveyed area separate diagrams have been constructed with the intention of obtaining a transparent information on the change of fragments distribution. Heights of column bars are proportional to the numbers of fragments in a particular class. The number of classes and their boundaries are displayed on the horizontal axis of the histograms.

Fig. 2 Muck-pile at the Velièanka quarry

It is possible to conclude from the diagrams (Figure 3) 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.

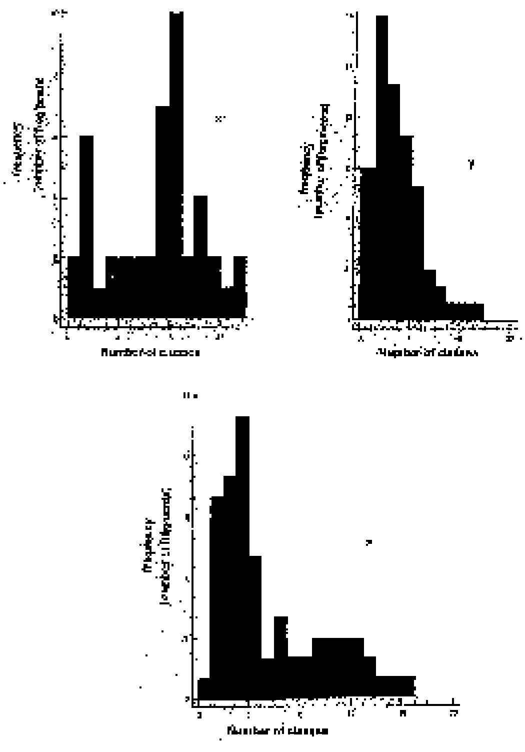

Fig. 3 Histogram of rock fragments after blasting along the x, y and z axis

Example 3. Open Pit Bukova Glava near Našice

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 (Figure 4) shows the distribution of the fragment along the *x*, *y* and *z* axes in the 3D space (in *cm*) [6].

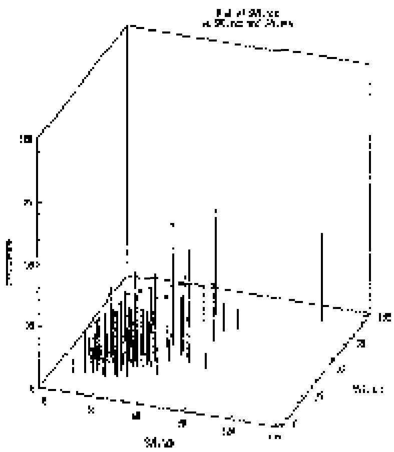

Fig. 4 Distribution of the fragment along the x, y and z axes in the 3D space

5.2 Screen analysis method

Example 4. Dolomite Quarry Dolje near Zaprešiæ

The 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 fragments sizes after blasting [7].

Figure 5 shows the results of data analysis for the dolomite quarry Dolje near Zaprešiæ.

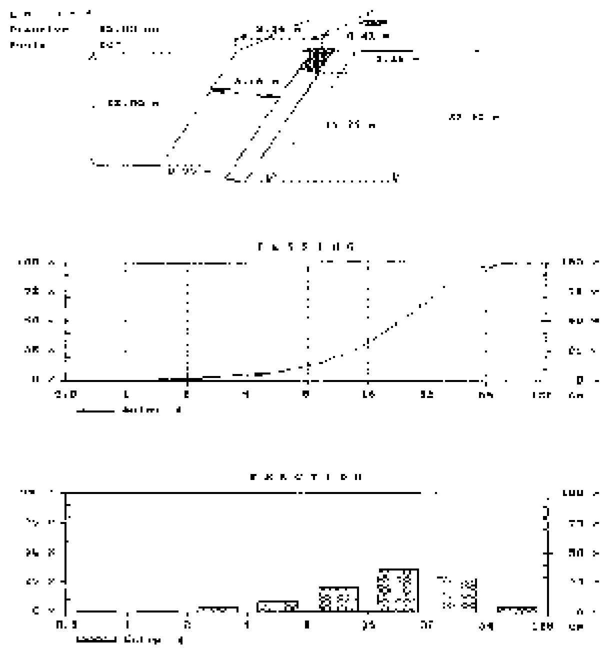

Fig. 5 Results of data analysis for the dolomite quarry Dolje near Zaprešiæ

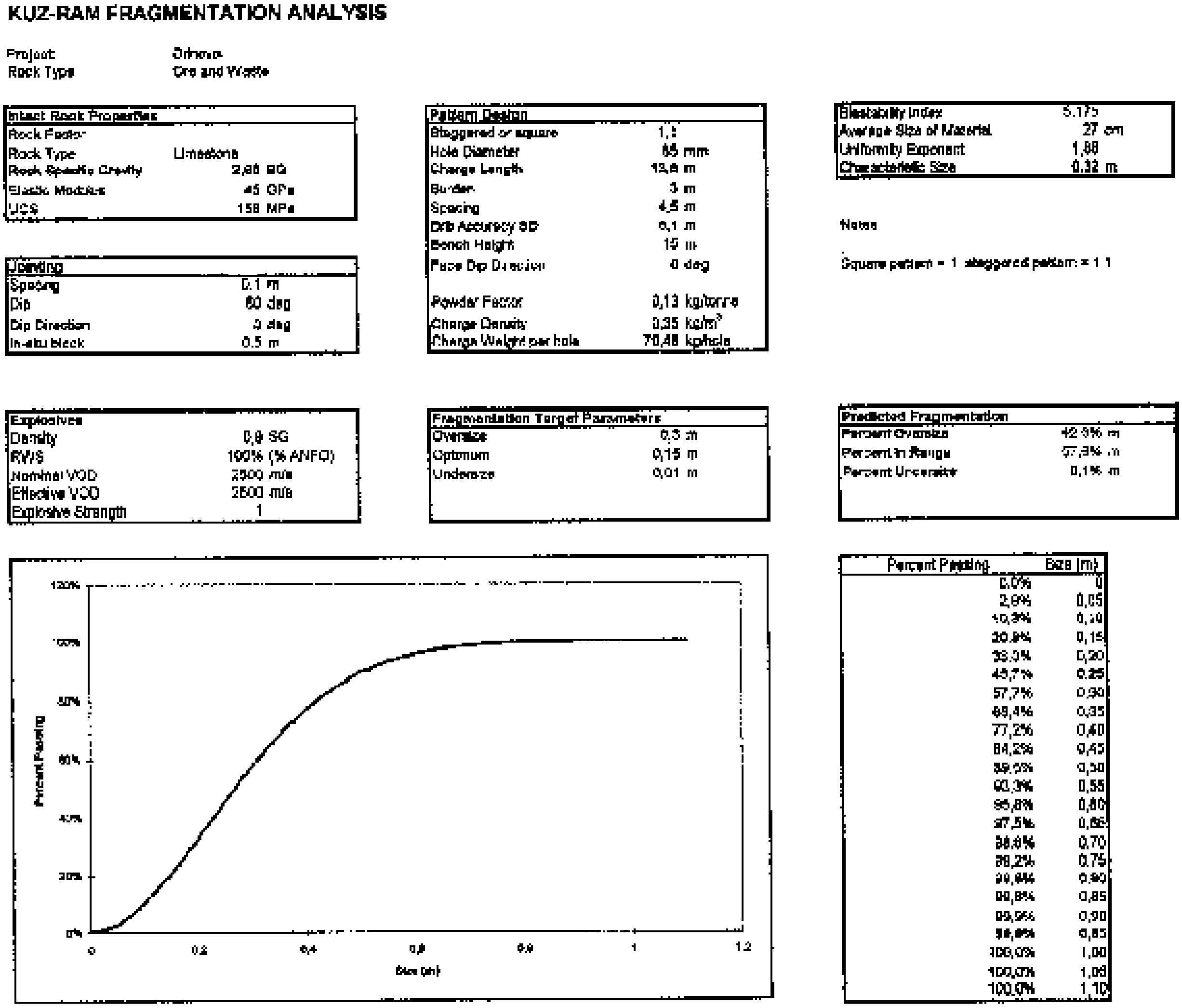

Fig. 6 Kuz-Ram fragmentation analysis

Example 5. Quarry Drinovci

The blasting can be so designed to represent an attempt to eliminate excessively big fragments or minimize the amount of fines in the rock muckpile. To obtain the most beneficial costs for the whole production process, the fragmentation must be optimal.

In the limestone quarry Drinovci fragmentation have been predicted by the Kuz-Ram model.

Figure 6 shows Kuz-Ram fragmentation analysis.

Example 6. Quarry Vrsi

For better understanding of the geological variation-quantifying problem, the blasting operations can be optimally designed, i.e. the rock factor correctly determined. The importance of the correctly determined rock factor value A is shown in Table 2 where by the use of the program "SB" a specific consumption of explosive (*p* in *kg/m'*) and burden (*B* in *m*) for different diameters of the blast hole and different rock factor values can be determined [8]. The different rock factor values were obtained by varying the joint dip only (horizontally, out of face, normal to face and into face). The values computed in Table 2 relate to the same cumulative participation of the fraction to *0.4 m* of *80%*, rock with joint spacing from *0.1* to *1.0 m* and the coefficient of density of blast holes *SB=1.5=m*. *S* is obtained as a computed value of the burden *B* for a given blast hole diameter, increased for *m=1.5.* The spacing value in this case is *S=1.5B*. All values in Table 2 represent approximate participation of individual classes according to Figure 7 and the participation of the fraction to *0.4 m* of *80%.*

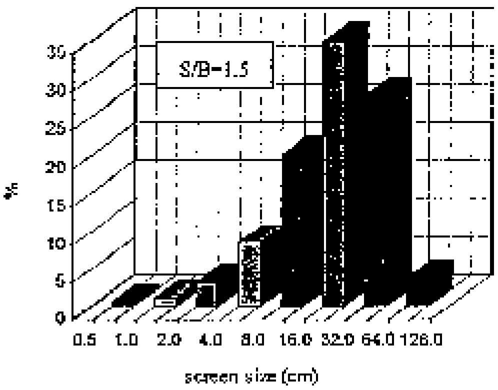

Fig. 7 Approximate participation of individual classes for the values in Table 2

Table 2 Dependence of the specific explosive consumption on different hole diameters and rock factors for the cumulative participation of the fraction to 0,4 m of 80%

Diameter of the blast hole (mm)	JOINT DIP (joint spacing from 0,1 to 1,0 m) horizontally (A=5,0)		out of face (A=6,2)		normal to face (A=7,4)		into face (A=8,6)	
	p (kg/m³)	burden (m)	p (kg/m³)	burden (m)	p (kg/m³)	burden (m)	p (kg/m³)	burden (m)
80	0,40	2,63	0,51	2,32	0,63	2,09	0,76	1,91
90	0,42	2,87	0,54	2,53	0,67	2,28	0,80	2,08
100	0,44	3,10	0,56	2,73	0,70	2,46	0,83	2,25
110	0,46	3,32	0,59	2,92	0,73	2,63	0,87	2,41
120	0,47	3,53	0,61	3,11	0,75	2,80	0,90	256
130	0,49	3,73	0,63	3,29	0,78	2,96	0,94	2,70
140	0,51	3,93	0,65	3,46	0,81	3,11	0,97	2,84
150	0,51	4,11	0,67	3,62	0,83	3,26	1,00	2,98

Figure 8 shows the diagram for the specific consumption of explosive as a function of drill hole diameter and rock factor A according to Table 2 and the participation of the fraction to *0.4 m* of *80%.*

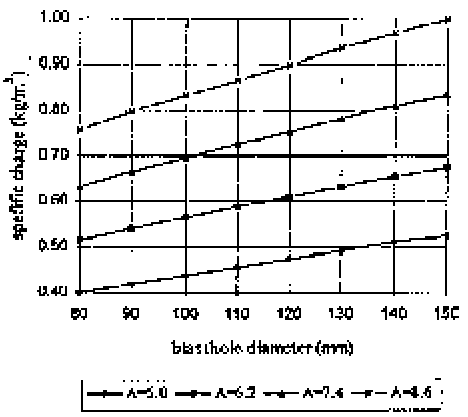

Fig. 8 Diagram of the specific explosive consumption in relation to the blasthole diameter and the rock factor

The right meaning of fragmentation in the blasting process is the actual gradation of the material at the entrance to the primary crusher. By the use of a computer model it is possible to design blasting that will increase the crusher capacity.

The required conditions can be simulated in the "SB" program for the required cumulative fraction participation to *0.2 m* of *50 %.*

After entering the values for bench height (*15 m*), explosive (ANFO), blasthole diameter (*86 mm*) and rock factor (*5.3*), the program computes the drill hole layout and displays the output data for the same specific explosive consumption in table form. The values computed in this way and simulated in the program, are shown in the Table 3.

The value *m* in Table 3 represents the density coefficient of the blastholes, *n* is the index of uniformity and x_c is a characteristic value for the material of blasted fragments.

As it is shown in Table 3, there are no sizes over *0.3 m* in the input material, as can bee seen out of the computed value of the characteristic sizes for different drilling layouts (the same specific consumption of explosive). The diagram of the values of the uniformity index and the characteristic fragment sizes (x_c) in relation to the density coefficient of the blastholes according to Table 3 is shown in Figure 9.

Table 3 The computed layout geometry for the required example

B (m)	S (m)	B × S	m	n	x_c (m)	cumulative fraction participation (%) 0,20	0,25	0,40	0,60
2.37	3.55	8.41	1.50	1.48	0.256	50.00	61.88	85.53	97.05
2.41	3.49	8.41	1.45	1.46	0.257	50.00	61.71	85.13	96.81
2.45	3.43	8.41	1.40	1.44	0.258	50.00	61.54	84.73	96.55
2.50	3.37	8.41	1.35	1.42	0.259	50.00	61.37	84.31	96.28
2.54	3.31	8.41	1.30	1.40	0.260	50.00	61.20	83.88	95.99
2.59	3.24	8.41	1.25	1.38	0.261	50.00	61.02	83.44	95.67
2.65	3.18	8.41	1.20	1.35	0.262	50.00	60.84	82.98	95.34
2.71	3.11	8.41	1.15	1.33	0.263	50.00	60.65	82.51	94.97
2.77	3.04	8.41	1.10	1.31	0.265	50.00	60.47	82.02	94.58
2.83	2.97	8.41	1.05	1.28	0.266	50.00	60.27	81.51	94.17
2.90	2.90	8.41	1.00	1.26	0.268	50.00	60.08	80.99	93.72
2.98	2.83	8.41	0.95	1.24	0.269	50.00	59.88	80.45	93.24
3.06	2.75	8.41	0.90	1.21	0.271	50.00	59.67	79.88	92.72
3.15	2.67	8.41	0.85	1.18	0.2273	50.00	59.45	79.30	92.15
3.24	2.59	8.41	0.89	1.16	0.275	50.00	59.23	78.68	91.55

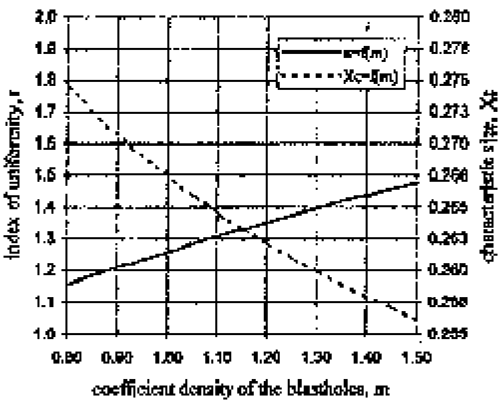

Fig. 9 Dependence of the uniformity coefficient and the characteristic value on the density coefficient of the blastholes

The fragment size distribution is commonly determined by changing the spacing between blastholes and between rows of the blastholes.

In addition, the program "SB" shows, according to Table 3, a diagram (Figure10) of cumulative dependence of selected fractions on the density coefficient of the blastholes.

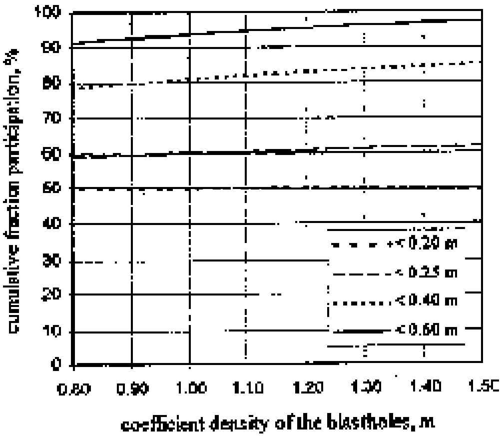

Fig. 10 Diagram of the cumulative dependence of selected fractions on the blasthole density

Example 7. Quarry O èura

Gold Size [9] is a Windows based computer program to estimate the sizes of blast fragmentation size distributions. Rocks are traced manually using computer's mouse pointer (Figure 11).

With practice it is possible to digitize approximately *100* rock fragments in *10* minutes using a computer mouse. The program provides a true scale display of all particles in a sample rather than their apparent size as shown in the samples image. It also demonstrates the definition of the particle size by finding and drawing the minimum bounding box around each scaled particle (Figure 12).

The width of the box is used to determine a particle size, because this most closely relates to standard seiving. The results can be presented by histogram and cumulative curves.

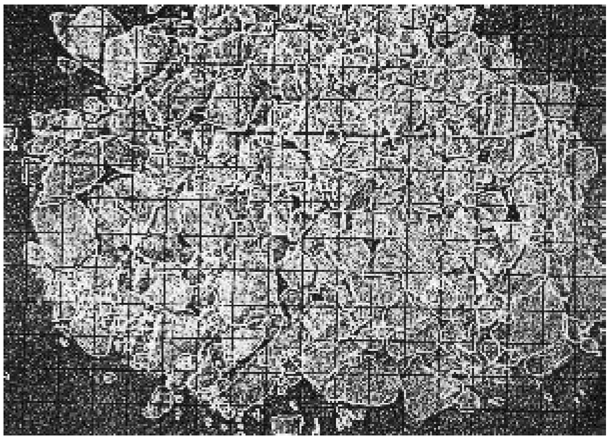

Fig. 11 Input image for processing

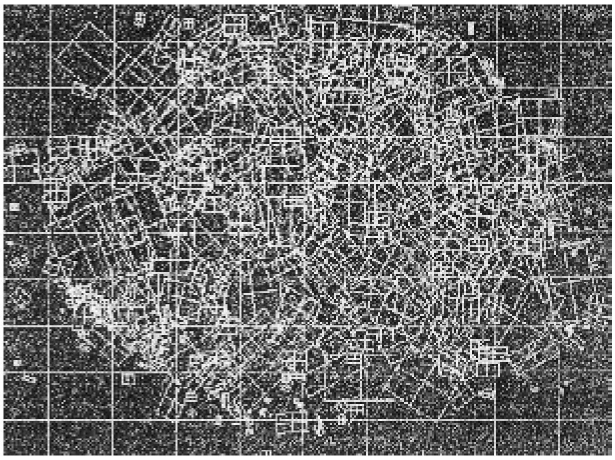

Fig. 12 Rectangular object contours

The histogram (Figure 13) shows the actual content of the sizing, whereas the cumulative view (Figure 14) is better for gaining an understanding of the form of the distribution and to compare different distributions.

In the automatic measurement process a computer programm identifies the rock contours.

However, together with the development of computer technology some photographic methods for the estimation of fragmentation have developed (Compaphoto, Wip-Frag, Split-Engineering, GoldSize and others). These methods show that the fragmentation can be evaluated by means of a set of photographs of the blasted rock mass.

The process starts with taking the photo of the muck pile in the quarry [10]. The photo is then digitized by a scanner. The scanner, which is the interface between image and digital information 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.

At Oèura Query, a fragment-size analysis of muck pile was carried out using sieves and analyzing fragment-pictures by program GoldSize. Figure 15 shows the fragment-size diagram of the muck pile after blasting by both methods used: sieving and analysis of pictures.

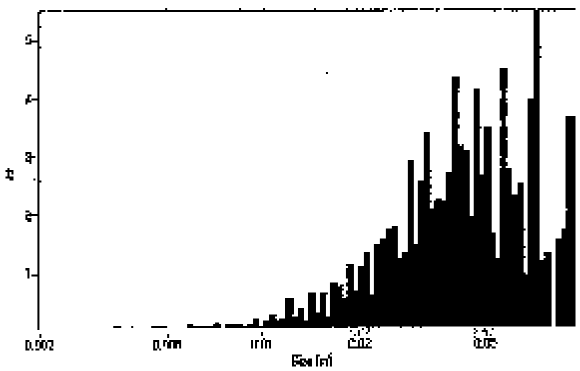

Fig. 13 Gold Size histogram

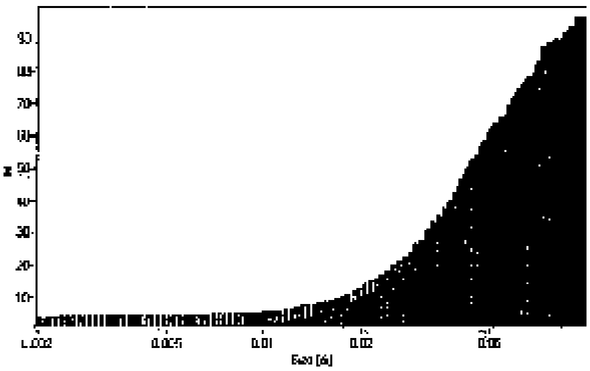

Fig. 14 Gold Size cumulative curve

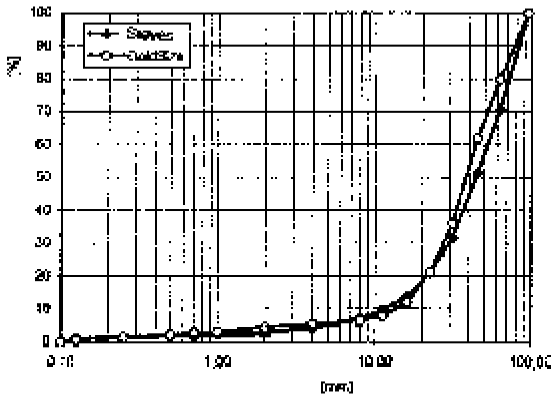

Fig. 15 Fragment-size diagram determined by sieves and by using fragment pictures

6. CONCLUSION

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

A fundamental requirement for advancing the science and technology of blasting is ready access to relevant, high quality and timely data, in particular spatial data. Such data must be in a form that can be visualised instantaneously and used to assist blast design, modelling, monitoring and performance measurement.

More efficient blast instrumentation and objective performance measurement techniques are required to meet the increasing demands of mining contractors and operators. Depending on applications, in most cases fragmentation is the most critical blasting performance measure.

Important data include that which quantifies the effects of rock structure, geological information from 3D bench and front surface mapping, 3D rock mass movement immediately after detonation, fragmentation, muckpile shape and swell, diggability and flyrock. This requires new and innovative tools for safe, detailed and efficient spatial data acquisition, and automated processing and reconstruction of the object.

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.

Good blast performance is essential to an effective blasting program.

Substantial sums of money can be saved when blasting performance matches mining and excavator requirements. Production increases and cost savings accrue in the following areas:

- Increased excavator production rates, higher bucket fill factors, decreased bucket loading time;
- Reduced time lost moving boulders and cleaning hard toe;
- Reduced excavator maintenance and increased rope, tooth and adapter life;
- Reduced truck maintenance, especially regarding boxes, suspensions and tires;
- Reduced secondary breakage costs;
- Reduced delays due to crusher blockages.

The equipment and technology discussed in this article can play an important role in developing a high-quality blasting program.

The 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 face to improve the productivity and cost of all downstream processes.

During the last decade effective blast monitoring tools, effective blast design tools, flexible initiation systems, rock mass mapping and modelling 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 modelling 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 analyses which utilize specific hardware and software to quantify bidimensional picture entities such as area, perimeter, shape, size and orientation.

Nowadays that processing includes:

- *Change of scale and correction of slope angles:* use of a reference sample within the mack pile and correcting its geometric distortions;
- *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 dimensions and transform those in three dimensions or volumes.

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MONITORING ZA PROCJENU KVALITETE MINIRANJA I ZA PREDVIĐANJE FRAGMENTACIJE

SAŽETAK

Fragmentacija (usitnjavanje) stijene smatra se najvažnijim pitanjem pri proizvodnom miniranju zbog svog direktnog utjecaja na troškove bušenja i miniranja, a također na ekonomiènost kasnijih operacija utovara, prijevoza i drobljenja. Tijekom posljednja tri desetljeæa uèinjen je znaèajan napredak u razvoju novih tehnologija u miniranju. To uključuje poboljšanje modernih instrumenata za mjerenje, sve bolje i složenije raèunalske modele za projektiranje miniranja i predviđanje uspješnosti miniranja, te naprednije eksplozive i sustave za palenje. Definiranje fragmentacije je prvi problem koji se javlja kad se prouèava usitnjavanje pri miniranju. Distribucija èestica po velièini na odminiranoj masi može se toèno utvrditi sijanjem, ali to nije praktièno jer je previše skupo (mnogo rada i zaustavljanje proizvodnje) i zahtijeva previše vremena. Zbog toga su razvijene brojne metode za procjenu distribucije fragmenata stijene po velièini. Kako usitnjavanje stijene ovisi o mnogo varijabli, kao što su svojstva stijena, geologija lokacije, lokalne pukotine, sadržaj vlage i parametri miniranja, ne postoji cjelovito teorijsko rješenje za predviđanje distribucije po velièini nakon miniranja. Najèešæe se koristi Kuz-Ram model koji je prikazan u radu zajedno s popularnom foto-analitièkom metodom. Gold Size je raèunalski program pod Windowsima koji procjenjuje velièine distribucije za fragmentaciju nakon miniranja. Može se zakljuèiti da zbog pojaèane svijesti i znanja o utjecaju fragmentacije stijena pri miniranju na rudarske operacije i odgovarajuæe troškove, ekonomiènost površinskih kopova može biti unaprijeđena.

Autor je razvio minerski fragmentacijski model "SB" koji æe uzimati u obzir mehanizme pritiska na smicanje pri usitnjavanju kod miniranja, te æe biti u moguænosti predvidjeti mnogo toènije cijelu krivulju distribucije fragmenata, bez obzira na matricu mehanièkih svojstava stijene.

***Ključne rijeèi**: monitoring, kvaliteta miniranja, fragmentacija stijene.*