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Technical Note

Comparison of Fragmentation Measurements by Photographic and Image Analysis Techniques

By

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1. Introduction

The primary objective of rock blasting is fragmentation but it is extremely difficult to assess the degree of fragmentation. Sieving/screening is a direct and accurate method of evaluation of size distribution of particles or fragmentation. However, for production blasting, this method is costly, time-consuming and inconvenient. Therefore, indirect methods, such as photographic methods have been in use in blasting research (Rholl, 1987; Nie and Rustan, 1987; MacLachlan, 1989). With the advances in technology, digital images processing and analysis systems are becoming increasingly popular in fragmentation measurement due to their advantages over photographic methods.

Research work has been carried out all over the world in developing image analysis systems. Several countries/organisations have developed their own image analysis systems. Some of these systems include IPACS (Dahlhielm, 1996), TUCIPS (Havermann and Vogt, 1996), FRAGSCAN (Schleifer and Tessier, 1996), CIAS (Downs and Kettunen, 1996), GoldSize (Kleine and Cameron, 1996), WipFrag (Maerz et al., 1996), SPLIT (Kemeny, 1994), PowerSieve (Chung and Noy, 1996) and Fragalyst (Raina et al., 2002). Though these systems claim that they are suitable for rock fragmentation analysis, limited field experiments have been conducted so far to check the validity of the results. Liu and Tran (1996) revealed that the results of fragmentation determined by three different image analysis systems were not the same. Among the available image analysis systems, WipFrag and Fragalyst are used in India. It is not known whether the results of fragmentation analysis of the same blast by both the systems are comparable. With this in view, size distributions of 10 photographs of a dragline blast in sandstone rock were determined by WipFrag, Fragalyst and photographic (manual) methods and the same were compared.

2. Techniques Used for Fragmentation Analysis

Photographs of a blasted muck of a dragline bench in sandstone were taken at a regular interval of half-an-hour. Analyses of ten photographs were done by using three methods, namely manual, WipFrag and Fragalyst. The last two methods are based on image analysis.

2.1 Photographic/Manual Analysis

Delineating of fragments on each of the photographs was carried out manually. For this, photographs of $0.15\,\text{m} \times 0.10\,\text{m}$ size were printed. Each photograph was placed under the transparent paper by fixing it firmly with the help of pins. All the fragments were delineated on the transparent paper. Delineation was started with large fragments because they are having more effect on the results. It was tried to detect and delineate fragments as small as possible. The scale placed in the middle of the muck pile was used to convert the measured distance on the photograph to actual distance. The manual analysis of each photograph took about one to two hours.

Then, a xerox copy of the traced paper was placed on a graph paper. The area of the reference scale on graph paper was noted down and then a scale factor (actual area of scale/graph area of scale) was determined. For every identifiable fragment, the area covered by the fragment was measured by counting the number of small blocks on the graph paper covered by that fragment was multiplied with the scale factor. For converting the area into volume, the third dimension was determined using the method of equivalent circle of area (Maerz et al., 1987; MacLachlan et al., 1989). The parameters are calculated as follows:

$$\text{Equivalent diameter} = \text{SQRT } (4 * \text{Area}/\Pi),\ \text{m}$$
$$\text{Spherical volume} = \text{Area} \times \text{Equivalent diameter},\ \text{m}^3$$
$$\text{Weight of the fragment} = \text{Spherical volume} \times \text{density of the rock, kg}$$

2.2 Image Analysis Using Fragalyst and WipFrag

Fragalyst (Raina et al., 2002) is an image analysis system developed by CMRI Regional Centre, Nagpur (India) and Wavelet Group of Pune (India). This system consists of capturing video photographs of the muck pile, down loading the photographs to the computer, or capturing the photos of muck pile from field by digital camera/ordinary camera then converting the images to grey scale, image enhancement, calibration and blob (grain) analysis. With the aid of menu-driven software, it is possible to determine the area, size and shape of the fragments in a muck pile/grain aggregates on the basis of grey scale difference. The 2-D information available from software can further be processed for stereological analysis for 3-D information.

Table 1. Comparison of automatic and manual netting of fragments by WipFrag

Photo no.	Mean fragment size, m		Uniformity index		Characteristic size, m		No. of fragments		Maximum fragment size, m	
	A	M	A	M	A	M	A	M	A	M
1	0.53	0.45	1.11	1.21	0.90	0.56	761	418	2.28	1.29
2	0.72	0.57	1.45	0.95	1.01	0.69	576	350	2.15	1.67
3	0.31	0.41	1.47	0.60	0.44	0.60	1368	459	2.16	2.78
4	0.45	0.83	1.33	0.77	0.57	1.12	868	321	1.29	3.59
5	0.44	0.37	1.31	1.05	0.67	0.45	974	354	2.16	1.00
6	0.56	0.49	1.23	1.02	0.88	0.69	1001	294	2.78	2.15
7	0.27	0.46	1.16	1.08	0.42	0.55	484	269	1.67	1.29
8	0.54	0.49	1.38	0.89	0.78	0.66	777	407	1.80	2.78
9	0.40	0.43	1.48	1.24	0.56	0.53	1000	262	2.46	1.00
10	0.51	0.44	1.16	1.16	0.83	0.58	808	341	2.39	1.29

Note: A = automatic, M = manual.

WipFrag is an image analysis system for sizing materials such as blasted or crushed rock. It was developed by Wipware, Inc, Canada (Maerz et al., 1996). It accepts images from a variety of sources such as camcorders, fixed cameras, photographs, or digital files. It uses automatic algorithms to identify individual blocks, and create an outline 'net'. WipFrag measures the 2-D net and reconstructs a 3-D distribution using principles of geometric probability. The system allows various types of output according to individual requirements, including cumulative size distribution graphs and percentage passing at different sieve sizes. Both WipFrag and Fragalyst allow combining results from several images called merging.

Fragmentation characteristics such as mean fragment size, uniformity index and characteristic size were calculated using automatic and manual netting facilities of ten photographs for WipFrag and the results are compared in Table 1.

Automatic netting produced larger mean fragment size in some cases due to the failure of software to recognize boundaries between clusters of fine particles, which were counted as single fragment, said to be "fusion". In other cases, automatic netting produced lower mean fragment size as some large fragments were broken into many smaller fragments, said to be "disintegration". Disintegration plays a crucial role in results because it affects large fragments and large volume. Automatic netting also produced high values of uniformity index in almost all the cases due to false identification of fines as fragments and fission of some coarser fragments into smaller. Delineation of fragments in each photograph was done manually after auto netting, generated by the image analysis systems.

3. Comparison of Individual Results

The fragment size distribution curves for all 10 photographs (samples) determined by all the three methods are plotted in Fig. 1. The mean fragment size, uniformity index and characteristic size for all samples are also given in Table 2. The mean fragment size determined by one method differs from the other as much as twice and is not

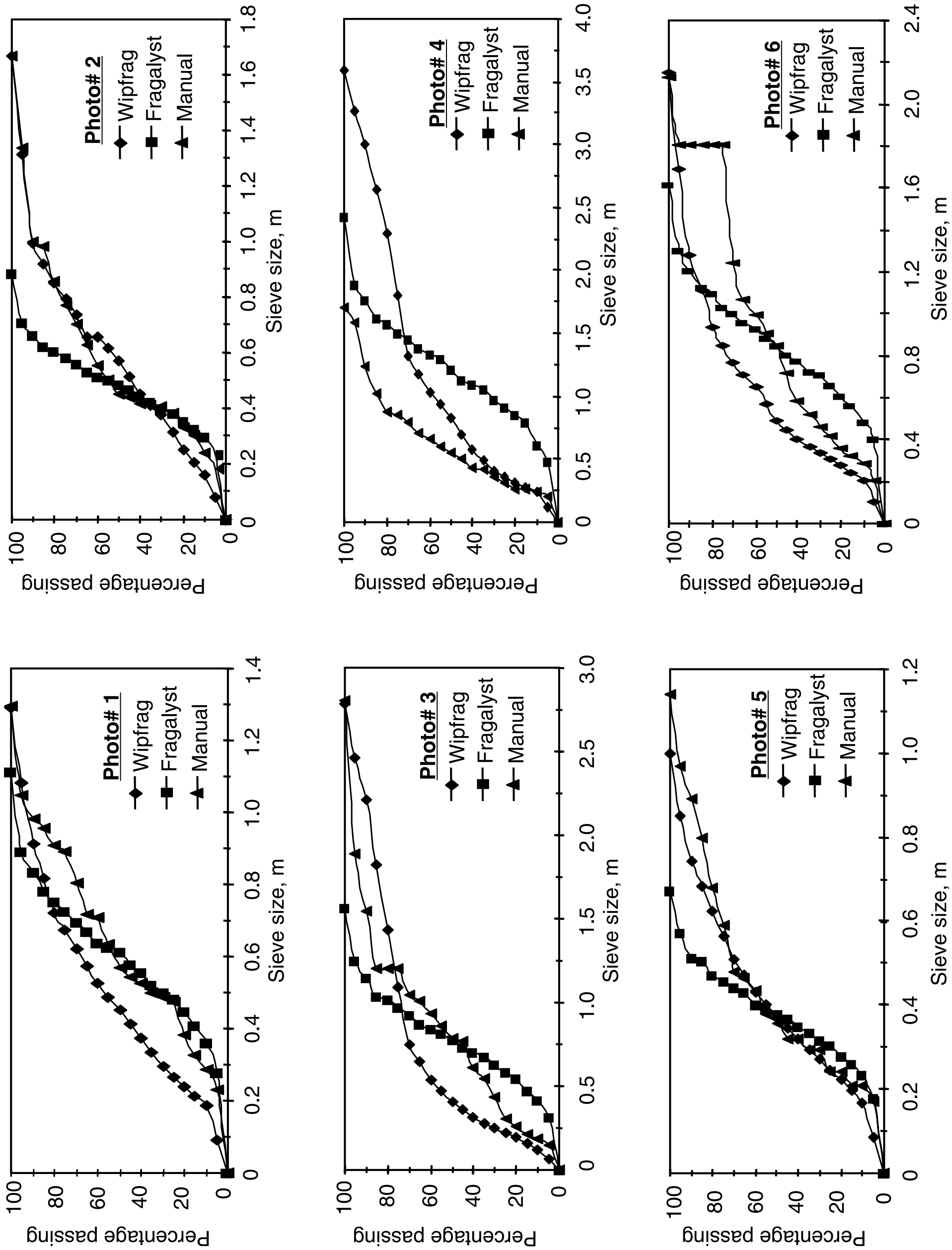

Fig. 1a. Fragment size distribution of individual samples (photographs 1 to 6) using WipFrag, Fragalyst and Manual method

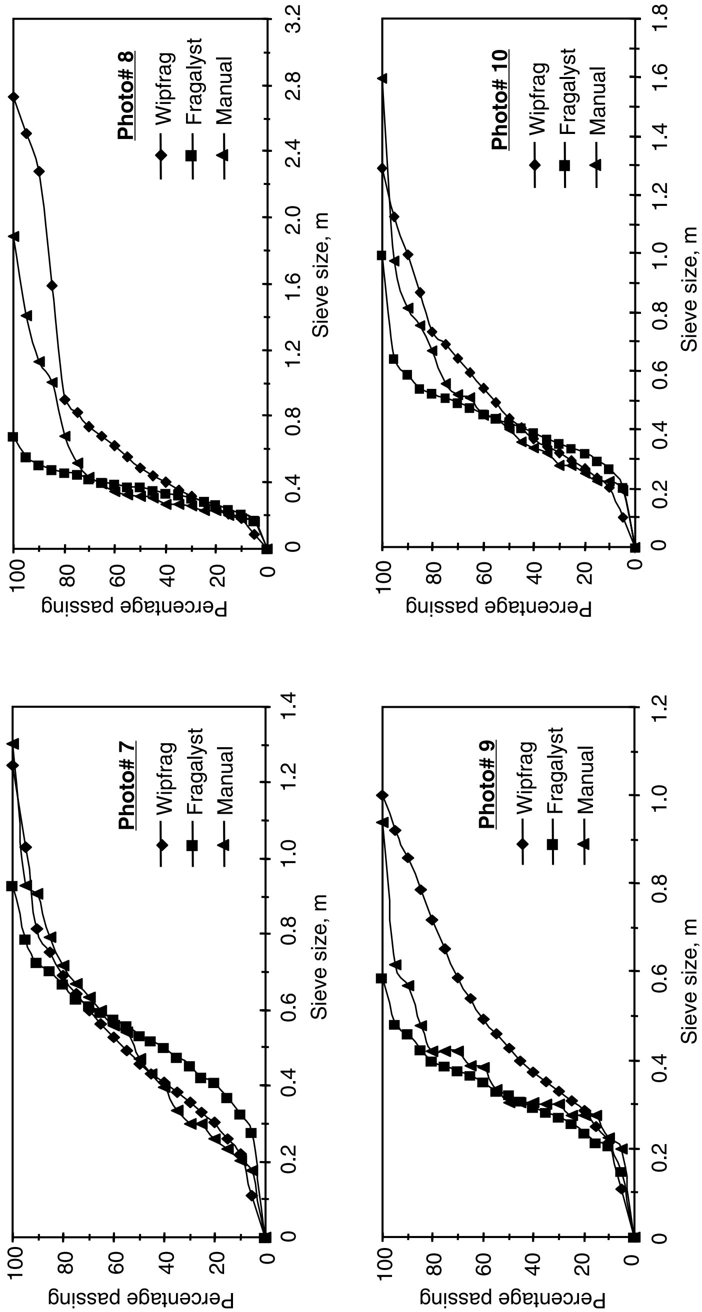

Fig. 1b. Fragment size distribution of individual samples (photographs 7 to 10) using WipFrag, Fragalyst and Manual method

Table 2. Fragmentation characteristics of 10 samples determined by Fragalyst, WipFrag and manual method

Photo no.	Mean fragment size, m			Uniformity index		Characteristic size, m		
	F	W	M	F	W	F	W	M
1	0.59	0.45	0.57	3.66	1.21	0.66	0.56	0.72
2	0.48	0.57	0.45	3.74	0.95	0.53	0.69	0.57
3	0.76	0.41	0.79	3.19	0.60	0.85	0.60	0.93
4	1.19	0.83	0.55	3.22	0.77	1.33	1.12	0.69
5	0.37	0.37	0.36	3.92	1.05	0.41	0.45	0.45
6	0.84	0.49	0.85	3.51	1.02	0.93	0.69	1.07
7	0.53	0.46	0.47	4.02	1.08	0.58	0.55	0.59
8	0.36	0.49	0.31	3.64	0.89	0.40	0.66	0.39
9	0.32	0.43	0.31	3.68	1.24	0.35	0.53	0.38
10	0.42	0.44	0.40	3.94	1.16	0.46	0.58	0.51

Note: F = Fragalyst, W = WipFrag, M = Manual.

consistently higher or lower for a particular method. Fragalyst indicates lower percentage of fines than the other two methods. At 100% passing, WipFrag and manual methods show larger fragment sizes compared to Fragalyst. The size distribution curves for manual analysis are not as smooth as for other methods.

The uniformity index estimated by Fragalyst is always greater than 3, which according to Cunningham (1983) corresponds to very uniform distribution, not common to blasted muck pile. The uniformity index obtained from WipFrag on the contrary is less than 1.5, which is normally expected in practical mining conditions. The maximum size of fragments at 100% passing computed by Fragalyst is much smaller than by other two methods. It appears that Fragalyst has underestimated the range of fragmentation, leading to higher uniformity index.

The difference in the fragmentation results could be due to different capability of the methods in detecting edges of fragments, resolution of fines and areas to volume transformations.

4. Comparison of the Merged Results

As the fragmentation within a blast was not uniform, several images were merged to estimate the representative size distribution of the blast. Though it was not possible to cover the entire muck pile of a dragline blast with these 10 photographs, yet the merged results were obtained in this study. The merging facility was available with WipFrag and Fragalyst. In case of the manual method, all the individual results of 10 photographs were combined and mass passing percentage at various sieve sizes were found. The merged results of all of these methods are shown in Fig. 2.

Manual and WipFrag analyses produced similar distributions but Fragalyst produced coarser results. The difference in the mean fragment size was 2.6% between WipFrag and manual analysis whereas it was 30.3% between Fragalyst and WipFrag. Possibly, Fragalyst underestimated the percentage of fines, resulting in coarser fragmentation.

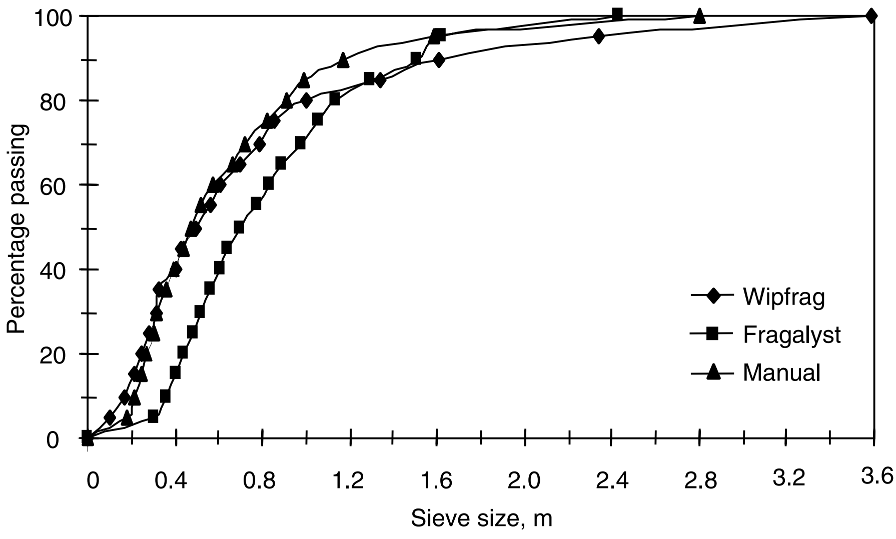

Fig. 2. Merged results of WipFrag, Fragalyst and Manual analysis

5. Correction of Fines Using Rosin-Rammler Equation

A major part of the explosive energy in rock blasting is consumed in creation of a significant amount of fines. The comparison of results of three image analysis systems, FRAGSCAN, WipFrag and SPLIT with sieve analysis results showed that the fines were underestimated by all the three systems because fines were hidden between the coarser fragments or they are simply too small to be resolved. As a result, image analysis tends to overestimate the mean size of the distribution and underestimates the variability of the distribution.

In order to estimate the fines and boulders, the Rosin-Rammler equation (Cunningham, 1983) has been applied. This equation has been extensively used in comminution and blasting and is given by:

$$R = e - (X/Xc)^n, \tag{1}$$

where

R = Factions retained on the screen,
X = Sieve size, m
Xc = Characteristic size, m
n = Uniformity index

Table 3. Adjusted characteristic size and uniformity index

	Measured from Fig. 2		Calculated from Eqs. (2) and (3)	
	k_{50}	k_{80}	Xc	n
Manual	0.49	0.99	0.67	1.18
WipFrag	0.70	1.13	0.86	1.76
Fragalyst	0.48	0.91	0.63	1.31

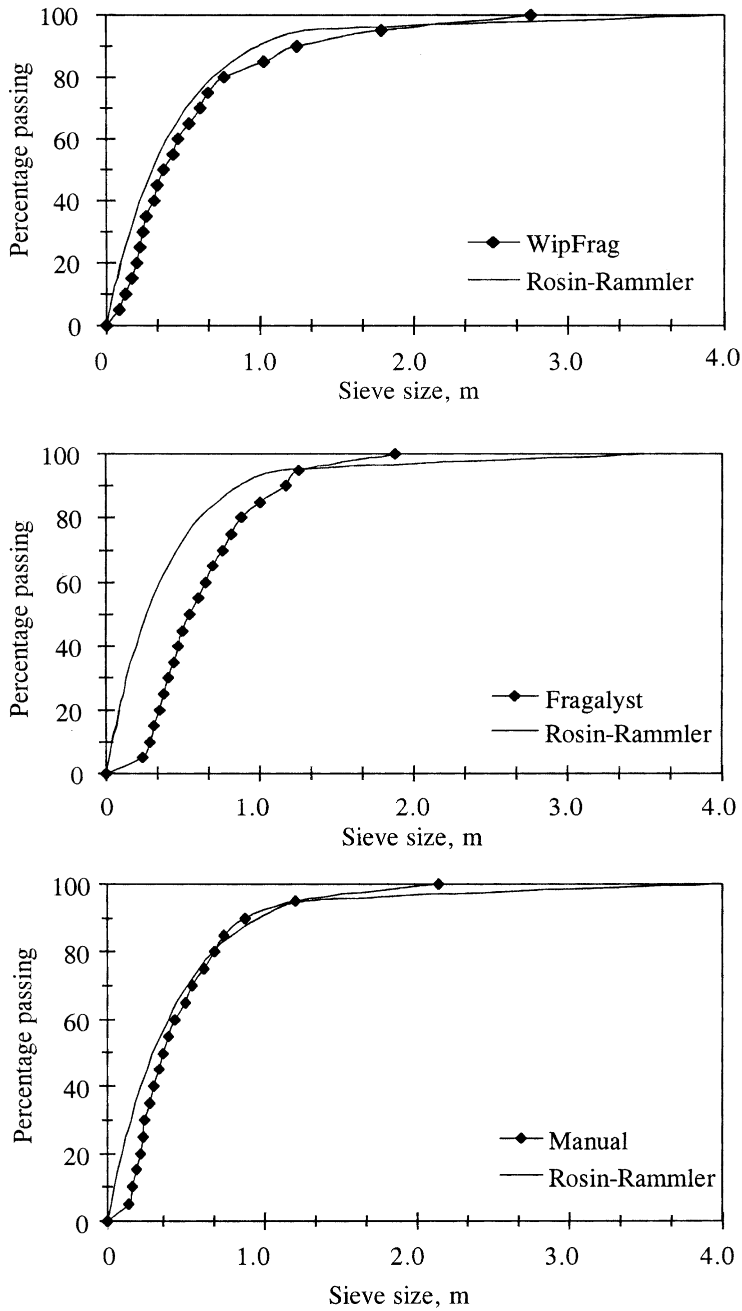

Fig. 3. Comparison of measured fragmentation with the adjusted Rosin-Rammler curve for WipFrag, Fragalyst and Manual analysis

This equation requires two parameters Xc and n to calculate the entire range of size distribution. These parameters could be calculated from the KUZRAM Model (Cunningham, 1983). This was not done because Chung and Katsabanis (2000) noted serious discrepancies between actual and computed uniformity indices. To overcome these discrepancies, the following empirical relations were suggested for calculation of Xc and n.

$$Xc = e^{0.565 \times \ln k_{50} + 0.435 \times \ln k_{80}}, \tag{2}$$

$$n = 0.842/(\ln k_{80} - \ln k_{50}), \tag{3}$$

where,

k_{50} = Sieve size at 50% material passing, m
k_{80} = Sieve size at 80% material passing, m
Xc and n as defined in Eq. (1).

The k_{50} and k_{80} values were taken from the merged results and the values of Xn and n were calculated (Table 3). After converting the fractions retained into percentage passing, the Rosin-Rammler curves corresponding to the measured distributions are shown in Fig. 3. The deviation of the sieve size at k_{50} from the adjusted Rosin-Rammler curve is about 26% for WipFrag, 107% for Fragalyst and 24% for manual analysis. This indicates that Fragalyst is the least accurate with respect to fines content and needs further improvement.

6. Conclusions

Fragmentation measurements of ten samples were carried out using a manual (photographic) and two image analysis systems. The photographic method was slow and the automatic netting facilities available with the image processing and analysis systems were not sufficient and required manual editing to improve the fidelity of the netting. The fragmentation results from three methods did not agree for individual samples. When merged, WipFrag and manual analysis produced nearly identical distributions but the Fragalyst results deviated significantly. The merged results were uniform and hence, the merging of several individual images for the same blast should be done to get the distribution of the entire muck pile. The Rosin-Rammler curves fitted to the merged distributions showed close agreement between the two in case of manual and WipFrag analyses. The curve deviated remarkably in case of Fragalyst, which appears to have underestimated the fines. Further improvement should be done to overcome the present limitations to make image analysis a practical tool for rock blasting.

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