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Photographic determination of oversize particles in heaps of blasted rock

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SYNOPSIS

A back-analysis procedure based upon 35 mm photography was developed on a laboratory scale for the purpose of determining the percentage of oversize particles known to be present in heaps of fragmented rock.

Eight simple blends of crushed stone containing varying percentages of oversize on a 1:40 modelled scale were examined. Simulated test conditions for the following were subjected to the photographic study: (1) a bench heap, (2) the surface exposure of a partially excavated heap, (3) a gravity-sorted surface as occurs on an apron dump, and (4) four quadrant views of an incrementally built conical heap of rock fragments.

The best back-analysis determinations were obtained from (4), the cone, over all eight blends of fragments. The mean error was within −0,16 per cent of the true value, with a range of ±1,872. This was for oversize contents of 5 to 20 per cent where a minimum 25 per cent of the photograph area was processed by digitizer. The worst results were from the apron dump at −1,462 per cent for a mean error of ±4,174 per cent. The intermediate results were from the undisturbed bench at −0,186 per cent with a mean error of ±2,862 per cent.

SAMEVATTING

Daar is 'n terugontledingsprosedure wat op 35 mm-fotografie gebaseer is, op 'n laboratoriumskaal ontwikkel vir die bepaling van die persentasie bogroottepartikels wat daar in hope gefragmenteerde rots aanwesig is.

Agt eenvoudige mengsels vergruisde klip word wisselende persentasies bogroottemateriaal op 'n gemodelleerde skaal van 1:40 bevat, is ondersoek. Gesimuleerde toetstoestande vir die volgende is aan die fotografiese studie onderwerp: (1) 'n traphoop, (2) 'n gedeeltelik uitgegraafde hoop waarvan die oppervlak blootgestel is, (3) 'n gravitasiegesorteerde oppervlak soos wat op 'n skorthoop voorkom, en (4) vier kwadrantaansigte van 'n inkremente opgeboude koniese hoop rotsfragmente.

Van al die fragmentmengsels is die beste terugontledingsbepalings van (4), die keël, verkry. Die gemiddelde fout was binne −0,16 persent van die ware waarde, met 'n strek van ±1,872. Dit was vir 'n bogrootte-inhoud van 5 tot 20 persent waar minstens 25 persent van die foto-oppervlakte met 'n versyferaar geprosesseer is. Die swakste resultate was afkomstig van die skorthoop, nl. −1,462 persent vir 'n gemiddelde fout van ±4,174 persent. Die tussenresultate was afkomstig van die onversteurde trap, nl. −0,186 persent met 'n gemiddelde fout van 2,862 persent.

Introduction

For the purpose of optimizing blasting operations, attempts have been made to evaluate and predict the size distribution of the fragments in a blasted muckpile[1,2]. Commonly, the approach has been to derive size-distribution equations, or to modify the comminution equations used in mineral processing[3-11]. Such efforts have been severely handicapped by the high costs involved in the sizing of fragments in full-scale field blasts. Consequently, operators and others have used visual observations of blasted rock piles to assess the effectiveness of the blasting practices used.

A widely used visual-evaluation procedure involves photography incorporating an included or applied grid plus a scaling reference[12,13]. As this system has not been calibrated, no good estimate of its precision has been possible. The tests described in this paper are based on the photographic analysis of fragment heaps of known composition, which indicates the precision of the photographic analyses through comparisons with the known blend.

The effectiveness of explosives in breaking rock is usually based on the following criteria:

(1) fragmentation sizing of the broken rock,
(2) diggability of the broken rock,
(3) stability of the new face created by the blast, and
(4) overall operating costs.

While a qualitative assessment of the above criteria is relatively simple, there is a need for reliable quantitative data. High-speed films (300 to 500 frames per second) are used to observe and measure events, such as firing sequence, ground movement, and gas escape, that occur during the short-time periods typical of quarry and pit blasting[14-16]. Observations of the dynamic events provides many data relevant to drilling and blasting practice.

Still photography has also been used in blasting studies. The favourable features of this approach are as follows.

(a) Comprehensive records are possible in a minimum of time.
(b) There is little interference with production activities.
(c) The records are permanent and can be subjected to review and analysis.
(d) Equipment and material costs are modest, and the practice can readily be instituted at operations.

Still photography may be used in studies of the structural characteristics of rocks that influence blast fragmentation[17]. Still photography may also be used as an aid in the characterization of field muckpiles through photo-

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graphic analysis of laboratory-scale reference models. An interesting approach was recently reported by Van Aswegen and Cunningham[18,19]. The present paper describes a study of the precision of photographs in determining the content of oversize fragments in a muck heap.

Experimental

The tests were aimed at an evaluation of the method in the quantitative detection of oversize fragmentations in muck heaps. A volume of 75 cm × 37,5 cm × 50 cm was used to simulate a 1:40 scale representation of a bench of 30 m × 15 m × 20 m. The oversize was based on a screen size of 50 mm (simulating a 2 m cube dimension) mixed into various finer fragments to simulate the fragmentation products of bench blasting. The details of the blend are outlined in Table I.

TABLE I

DETAILS OF THE TEST BLENDS USED IN THE EXPERIMENTS

	Size		Size		Size		Size	
Test no.	cm	%	cm	%	cm	%	Type	%
Test 1	5	5	2,54	–	1,27	25	Fines	70
Test 2	5	10	2,54	–	1,27	25	Fines	65
Test 3	5	15	2,54	–	1,27	25	Fines	60
Test 4	5	20	2,54	–	1,27	25	Fines	55
Test 5	5	5	2,54	5	1,27	25	Fines	65
Test 6	5	10	2,54	10	1,27	25	Fines	55
Test 7	5	15	2,54	15	1,27	25	Fines	45
Test 8	5	20	2,54	20	1,27	25	Fines	35

The reference muckpiles were subjected to the following test procedures in an attempt to simulate most of the situations that are encountered in actual openpit mining operations:

(1) a normal working bench:
  (a) immediately after a blast and
  (b) the same bench in a partially excavated condition;
(2) a sidecast heap in the form of a cone; and
(3) an apron dump (dump tallus).

Bench Model

To simulate the conditions of a working bench, a wooden box in which the inside dimensions were equal to the scaled dimensions of the bench was constructed in such a way that two adjacent sides could be released to spill its contents, thereby simulating a blast-fragmented bench.

For the test, the box was filled with thoroughly mixed test blends, and the two sides were opened out simultaneously. The two resulting slopes were then photographed. For (1)(b), a small scoop was used to incrementally remove approximately 25 per cent of the volume, and the resulting two new slopes were also photographed.

Sidecast Heap

A small hopper arrangement was fabricated to aid in the incremental building of a cone. The volume of the hopper was approximately 5 per cent of the total volume of the muckpile. The hopper was mounted on four vertical supports so that its height could be adjusted. This was done so that the cone could be built up in stages, newly added material being dropped from approximately the same height above the top of the cone as it was forming.

Before the cone was started, reference marks were laid out on its platform in order to facilitate the taking of oriented photographs in which the effects of distortion due to the curved surface of the cone would be minimized. In the laboratory tests, after the results from 4, 6, and 8 photographs had been compared, it was decided that, owing to the relatively small size of the cone, four quadrant photographs would be sufficient. For larger cones, more photographs would be required. In all cases, the photographs were taken as nearly as possible perpendicular to the slopes of the fragment piles, as illustrated in Fig. 1.

Apron Dump

To simulate the tallus slope of a waste pile, or ore stockpile, an apron dump was constructed from plywood boards. The front surface of the 'dump' was inclined at an angle slightly steeper than the angle of repose of the material to be handled (crushed limestone in this case). Two wooden boards were fixed to the sides to restrain the material from flowing to the back and thereby becoming inaccessible to the camera. The height of the dump was chosen to ensure a sufficient cover of material over its surface. In actual mining, the large size of most dumps ensures that the material is spread fairly consistently so that photographs of the active part of the dump would give a fair representation of the material being added at that point.

The test blend was spilled from the top edge of the model dump in small volumes. When all the material had been placed, the front surface of the dump was photographed.

Photographic Technique

A photographic approach was chosen for the following reasons.

(1) It is a rapid, simple operation (leading to minimum disruption of the mining operations in the field application).
(2) It provides accurate and comprehensive records.
(3) It lends itself to rapid analysis and routine use in production operations.
(4) Its cost is low, and the equipment required is fairly simple.

Fig. 1 shows the approach that was adopted. The principal guidelines were as follows.

(a) The photographs should be taken as nearly as possible normal to the plane of the muckpile slope.
(b) At least two spheres of known dimensions should be placed in view and distributed so that one of them would be near the top edge of the muckpile and another near the bottom edge.
(c) Two photographs should be taken at different exposures for each setup as a precaution against photographic errors.

Reference Muckpiles

Oversize material in a blast is of most concern to mine operators. Not only does it hinder the loading machine,

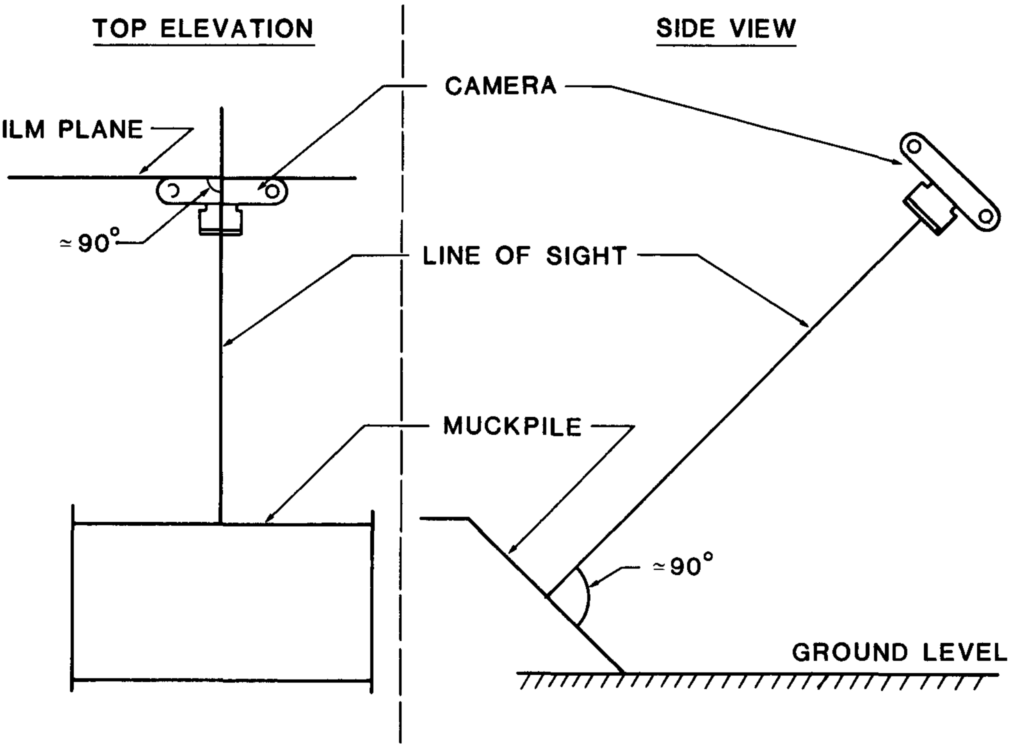

Fig. 1—Schematic diagram showing how the photographs were taken

resulting in costly delays and losses in production, but it also presents a safety hazard. An evaluation system that can recognize oversize material and determine the approximate percentages in a shot muckpile could be a very valuable aid to the mine operator wishing to take corrective action in blasting procedures, or in allocating and scheduling the available load-haul equipment.

Once the photographic determination of oversize material in muckpiles had been defined as the primary object of the study, several reference blends of crushed limestone were prepared. As previously mentioned, these are detailed in Table I.

At a scaling ratio of 1:40, the 5 cm screened particles represent oversize material of 2 m in a blast muckpile, while coarse material screening 2,54 cm is representative of fragments measuring 1 m.

Four blends (nos. 1 to 4) simulated the presence of 5, 10, 15, and 20 per cent oversize material with no coarse material. A constant 25 per cent of material of intermediate size—1,27 cm (½ m)—and fines completed the blend.

A second group of four blends (nos. 5 to 8) was also prepared. These blends contained coarse as well as oversize material, a constant 25 per cent content of intermediate-size material, and corresponding quantities of fines.

All eight blends were subjected to the muckpile procedures already described, and to photographic analysis. Two different approaches were used for the determination of the size distributions of the muckpiles.

Grid Sampling

In the first approach, the object was to make a complete sizing analysis of the muckpile, excluding the fines, which were subsequently determined by subtraction. The development of a grid-sampling technique was essential if digitizer processing of the entire photographs was to be avoided.

A complete digital analysis of the fragmentation visible in the photographs was neither essential for the processing, nor justifiable in terms of the processing costs. Noren and Porter[20] report a sampling of 15 per cent or less of the muckpile surface as sufficient for the purposes. A suitable and somewhat higher sampling intensity was established as described for the present study.

First, a range of detailed fragmentation measurements representing 20 to 30 per cent (in 5 per cent increments) of the photograph area was established. This was done by the selection of grid areas, as illustrated in Fig. 2, for detailed digitizing, and by variation of the dimensions of the superimposed grid. From a comparison of the derived size distributions with those known to be present, it was found that the sampling areas representing 25 per cent or more of the total area gave fairly consistent results. Consequently, for all the grid-sampling tests, at least 25 per cent of the sample area was measured.

Measurement of Total Oversize Area

The second approach was to digitize all the oversize particles (and only the oversize particles) in the muckpile photograph. All the obviously oversize fragments were detected by the measuring of dimensions in two mutually perpendicular directions. The total area of all such fragments was expressed as a percentage of the total surface area of the muckpile as shown on the photograph. This percentage value was compared with the known percentage content of the oversize fragments in the muckpile.

Measurement of Fragment Size

The measurements of fragment size, which were based upon the grid-sampling approach, were made with a Carl Zeiss Digitizer. Within each sample space, all the particles except the fines were measured. The smallest particles

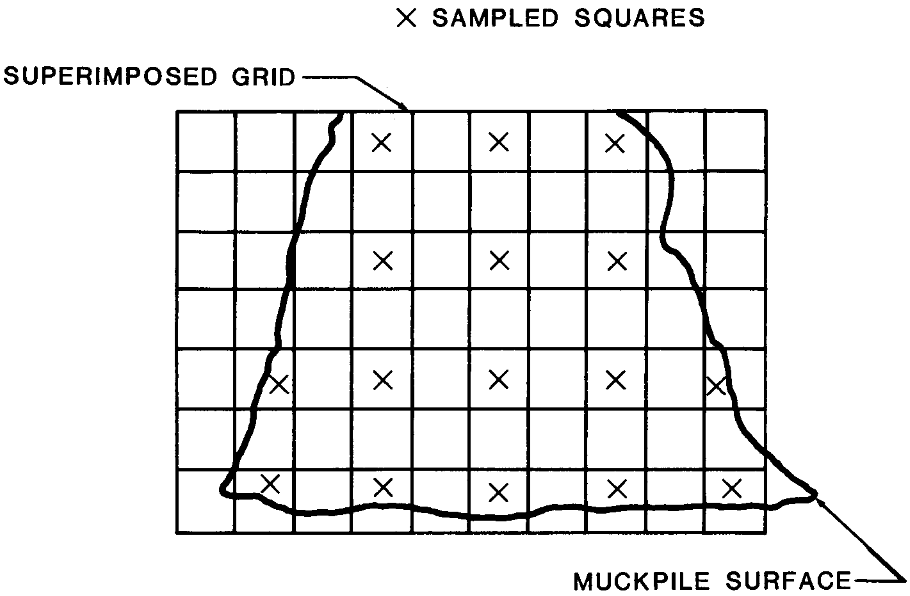

Fig. 2—Schematic diagram showing the method of random sampling used

measured were 1,27 cm on edge. The fines were determined by subtraction. Histograms of the fragment sizes measured were recorded automatically, and a comparison of these sizes with the sizes known to be present in the observed pile indicated the precision of the analytical procedures.

Scaling

In each photograph, two spheres of known dimensions were used to scale the measurements. As demonstrated in Fig. 3, the top half of the photograph, i.e. Part A, was referenced to sphere X, while the lower half, or Part B, was referenced to sphere Y. The effects of distortion were thereby restricted to a smaller range from a known reference scale.

The computer automatically dimensioned all the subsequent measurements according to the reference scale measured at the start. Some guidelines were followed for the particles that were difficult to measure in a straightforward way. All the particles that were partially covered by fines were measured as follows: the cursor was traced along the exposed boundary and then judgement was used, based on apparent size and shape, to close the trace. Nothing could be done about small fragments that were completely covered, and these were omitted from the measurements. In the case of particles overlapping other particles, the shortest closure path was followed. For particles that projected normally out of the muckpile, the actual size of the fragment exposed on the photograph was measured and was added to its appropriate size category if so seen from another photograph (side view).

Some of the fragments were not completely contained within the sample spaces (i.e. inside the grid squares). For such a fragment, if more than 50 per cent of it was inside the square, it was measured; otherwise, it was left out of the measurements. The same procedure was followed for particles falling between the dividing line of boundaries for the cone experiment, and the measurement was added to the view that contained more than 50 per cent of the particle.

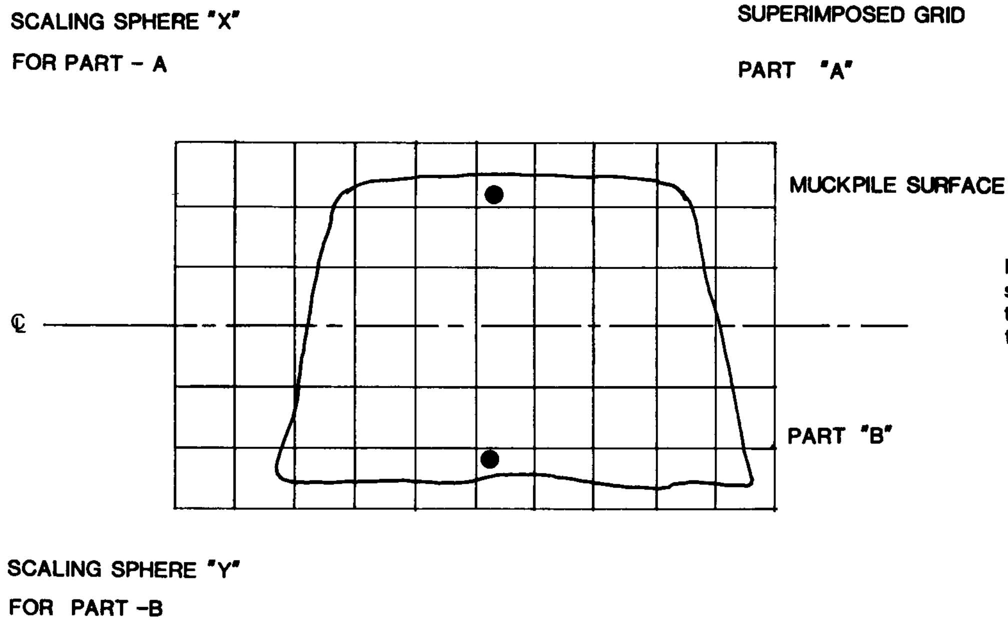

Fig. 3—Schematic diagram showing the method by which the top and bottom halves of the photographs were scaled

It should be pointed out that it was relatively easy to recognize the fragment components from the photographs when the number of the constituent sizes were few (test nos. 1 to 4, Table I), and also when smaller percentages of oversize were present. Difficulty arose with higher percentages of oversize and more constituent sizes (test nos. 5 to 8, Table I). The detection of fragment size consumed the maximum time. This technique involves considerable use of the computer, and without it the length of the detection and measurement process would be quite prohibitive.

Results

Table II summarizes the error differences between the percentage oversize content of the test blends as determined by both photographic processing procedures, and the actual values present in the known blends as listed in Table I.

TABLE II
THE MEAN ERRORS AND STANDARD DEVIATIONS FOR ALL THE TEST RESULTS

	Bench (undisturbed)	Bench (partially extracted)	Cone	Apron dump
Analysis of Sample Area				
Overall composition:				
Mean	-0,186	-1,116	-0,160	-1,462
Standard deviation	2,872	2,367	1,872	4,174
Overall composition (without 20% oversize test results):				
Mean	-0,541	-1,095	0,046	-0,523
Standard deviation	2,425	2,675	1,491	2,254
Analysis of Total Area				
Overall composition:				
Mean	0,632	-0,280	0,315	0,405
Standard deviation	1,566	1,058	0,962	1,997
Oversize composition (without 20% oversize test results):				
Mean	0,380	-0,425	0,354	0,202
Standard deviation	0,482	0,697	0,625	0,763

Such a verification of observed data against known conditions can be termed back-analysis. In this manner, some rigour can be applied to questions of the precision of photographic analysis. This aspect of photographic studies of blast fragmentation does not appear to have been addressed in the literature.

Since it is desirable and also expected, that there should be less oversize material than other material in a muckheap, Table II also gives the results for when the 20 per cent oversize blends had been removed.

Fig. 4 shows the ratio of the sampled area to the total volume of the muckpile, and Fig. 5 the ratio of total photographic area to heap volume for the various heap geometries studied. The values in Fig. 5 correlate with the errors and standard deviations in the total-area analysis based upon the detection of oversize only, which is the faster of the two approaches used.

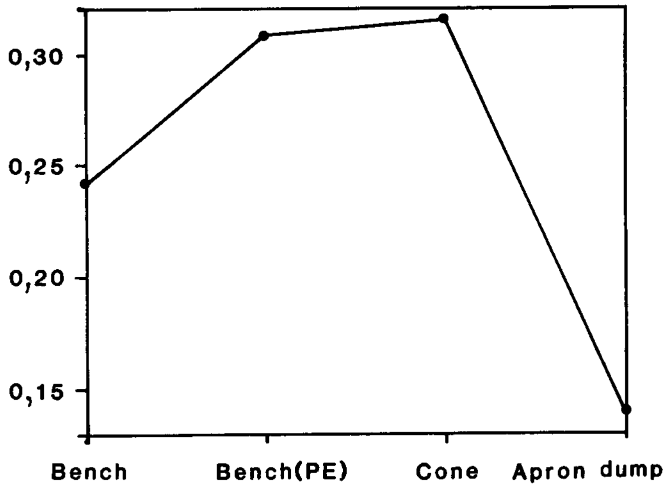

Fig. 4—Ratios of sampled areas to total volume

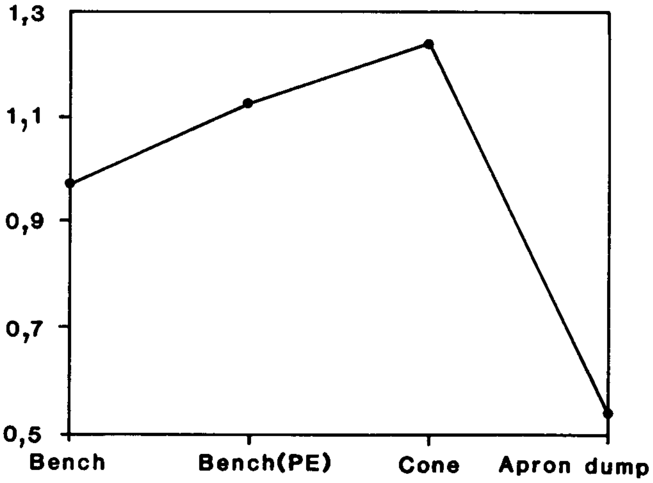

Fig. 5—Ratios of total area to total volume

In field applications, the desired ratio of photographic area to heap volume can be achieved by repeated photographing of a given heap as it is excavated. It should be noted that a reduced heap volume is associated with later photographs. For example, an openpit bench measuring 100 m long by 15 m high may be blasted to widths of 20, 40, and 60 m if 2, 4, or 6 rows of holes are fired. The bulking effects will result in a heap that is 10 per cent higher than the bench, and having a toe displaced 2½ to 3 times the bench height. The following approximate ratio of slope area to volume would be expected for the front and end areas of the initial muckpile volume, i.e. 0,189, 0,1093, and 0,0827 respectively.

An increase in the ratio of photographic area to heap volume can be obtained by the taking of photographs of the heap as it is excavated. This would lead to improved precision in the determination of mean and standard deviations for the oversize content present. However, as shown in Fig. 5 and Table II, a 100 per cent or more increase in the area-to-volume ratio for the cone versus the apron-dump configurations does not entail a corresponding increase in the precision of the oversize determinations.

One can therefore conclude that good results can be obtained from a less-intense analysis in field operations.

Conclusions

(1) The amount of oversize material in muck heaps as determined from photographs, in comparison with the known contents of reference blends, permits an evaluation of the precision of the approach, i.e. a back-analysis approach can be used.

(2) Comparable results are attainable (Table II) from the two photographic approaches used: a grid-sampling analysis of all the particles viewed, and a total-area analysis directed at measurements of only the larger fragments.

(3) The more rapid photographic analysis is that involving total area and oversize measurements.

(4) Of the heap geometries examined, the cone, which had the highest ratio of sample area to volume, gave the best results.

(5) Greater precision results from the use of larger area-to-volume ratios in the analysis. However, the improvement of precision with area-to-volume ratio is not very concisely defined, as can be noted from Table II and Figs. 4 and 5. The more than 100 per cent increase in area-to-volume ratio from the apron-dump geometry to the cone geometry does not involve a corresponding 100 per cent increase in precision. This may be interpreted to imply that field situations of lower area-to-volume ratio give values of lower precision although still of significant accuracy.

(6) Increases in area-to-volume precision may result from the taking of a series of photographs as the excavation proceeds.

(7) An alternative to the repeated photographing of a heap during excavation is the building up of a conical heap of samples selected from the excavating cycle. As shown in Table III, such a cone may contain 10 per cent of the total volume and, when subjected to the photographic process, estimates can be made of precision versus sample-cone volume.

TABLE III

ESTIMATED 90 PER CENT CONFIDENCE INTERVALS FOR SAMPLE CONE VOLUMES OF 10 TO 30 PER CENT OF THE HEAP VOLUME (ESTIMATES BASED UPON THE RESULTS GIVEN IN TABLE II)

	Analysis of sample area for the overall composition of fragment sizes		Total-area analysis for oversize composition	
Sample size %	Mean		Mean	
10	−0,439	0,119	0,172	0,458
15	−0,388	0,068	0,198	0,432
20	−0,357	0,037	0,213	0,417
25	−0,337	0,017	0,224	0,406
30	−0,321	0,001	0,232	0,398

(8) Depending upon the type of analysis desired, the appropriate test method can be selected. For a complete fragment-size composition of a blasted muckpile, photographs by the grid-sampling method would involve about 2 hours of digitizing. On the other hand, if only the oversize is required, the total-area approach would take less than 30 minutes.

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