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WipFrag Image Based Granulometry System

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ABSTRACT: Quick and accurate measurements of size distribution are essential to managing fragmented rock and other materials. WipFrag is an automated image based granulometry system that uses digital image analysis of rock photographs and video tape images to determine grain size distributions.

WipFrag images can be digitized from fixed video cameras in the field, or using roving camcorders. Photographic images can be digitized from slides, prints or negatives, using a desktop copy stand. Digital images in a variety of formats, delivered on disk or over electronic networks, can be used.

WipFrag uses powerful image analysis techniques to isolate the individual fragment boundaries. Edge detection is optimized by setting Edge Detection Variables (EDV). Manual editing can be used to improve the fidelity of edge detection.

WipFrag has the facilities for zoom-merge analysis, where the combined analysis of images taken at different scales of observation can be used to overcome the size limitations inherent with a single image. Alternatively, an empirical calibration mode is available.

1 INTRODUCTION

Quick and accurate measurement of fragmented rock is essential in the blasting, mining and materials handling industries (Maerz, 1990; Maerz et. al., 1987a; Maerz et. al., 1987b; Franklin and Maerz, 1987).

In the blasting industry, accurate fragmentation measurements can be used to evaluate different explosives, blasting patterns, and delay timing. It can be used along with insitu block size (Maerz and Germain, 1996) to evaluate the efficiency of the blasting, and the accuracy of blasting simulations. It can be used to optimize all blasting parameters to reduce costs.

In the mining and quarrying industries, accurate measurements can be used to monitor and optimize the production of fines which absorb and waste a sizable proportion of the explosive energy, encourage unwanted oxidation, and can lead to densification and ore blockages. Also, measurements can be used to reduce oversize (which results in excessive loading and hauling costs, expensive secondary blasting or crushing, and excessive wear on equipment).

In the materials handling industries, sizing measurements can to used to guarantee that specifications are met, especially with the newer blended aggregate systems. Delays and congestion in loading and transportation caused by excess of fines or oversized and slabby blocks can be minimized.

2 IMAGE PROCESSING SYSTEMS

Digital image processing systems are becoming increasingly employed in industrial applications, not just in research. With the advent of inexpensive fast computing power, improved image processing techniques and algorithms, and the availability of inexpensive, portable and light-sensitive video cameras, sizing of materials is now becoming routine.

Image based methods of analysis have many advantages over traditional sieving (screening):

1. Image processing is quick; multiple images can be taken quickly, and also analyzed quickly.

2. Image processing, because of its speed does not interfere with or disrupting production.

3. Because image processing is inexpensive and fast, many samples can be analyzed, making sampling errors less significant.

4. The sheer quantity and variability of blast fragmented rock make screening entirely impractical, except for occasional research work. Image processing on the other hand, is not limited by size of volumes of rock.

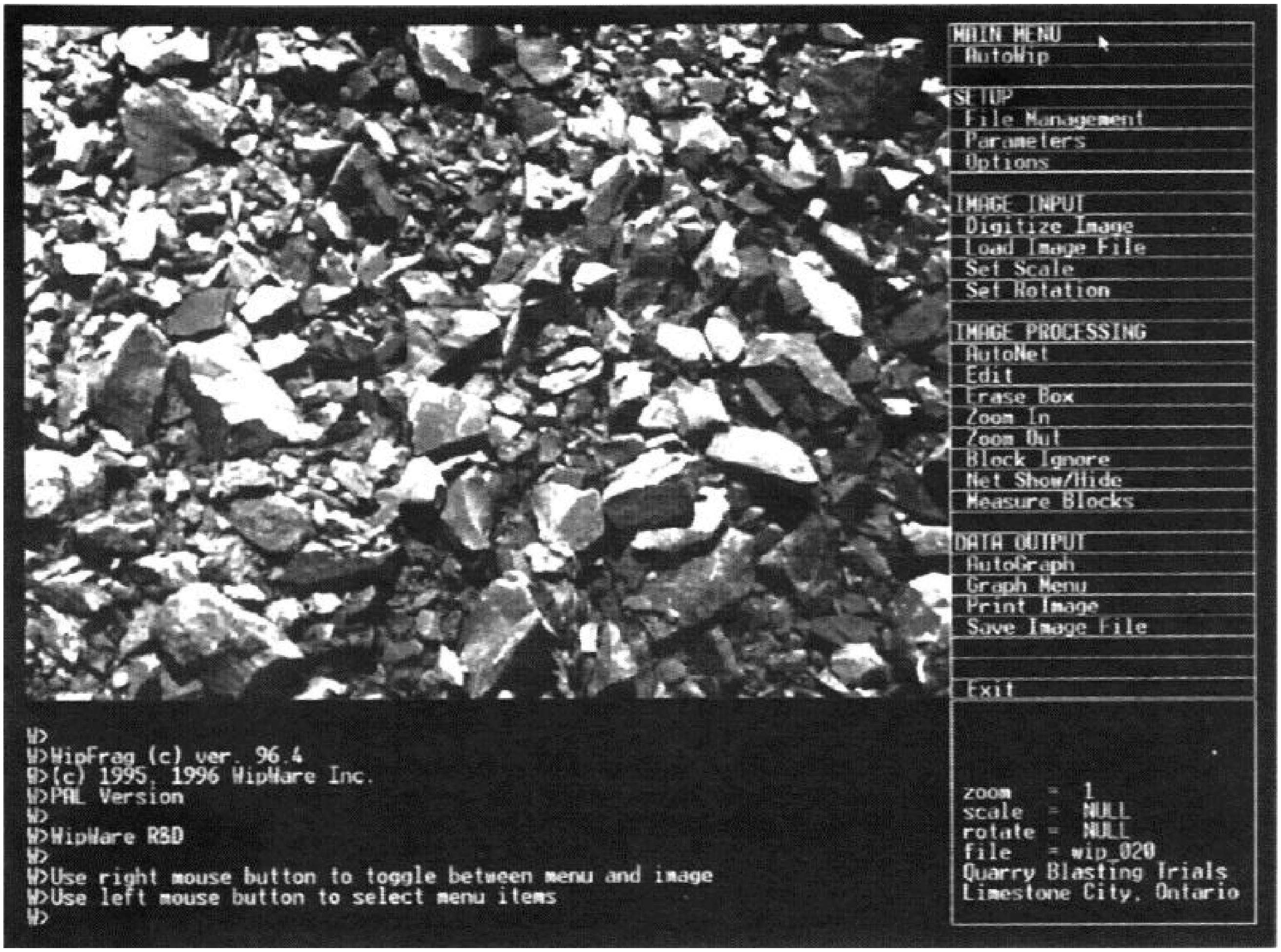


Figure 1. WipFrag Main Screen

5. An added bonus is that digital image analysis is non-destructive and therefore ideal for measurements on weak rock and ore (e.g. coal, gypsum) which tend to break down when screened.

3 THE WIPFRAG SYSTEM

WipFrag is an image analysis system for sizing materials such as blasted or crushed rock (Palangio, 1985; Palangio et. al., 1985) (Figure 1). It has also been used to measure other materials, such as ammonium nitrate prills, glass beads, and zinc concentrates (Figure 2).

From its inception about 10 years ago, WipFrag and it predecessor WIEP have been designed to take full advantage of the flexibility of general purpose microcomputers (in contrast to purpose designed image analyzing computers, which being designed for metallurgical or medical use place a number ofundesirable constraints on the use in mining and quarrying). This flexibility is apparent at image input, processing, and output stages of analysis.

WipFrag accepts images from a variety of sources such as roving camcorders, fixed cameras, photographs, or digital files.

It uses automatic algorithms to identify individual blo cks, and create an outline "net", using state of the art edge detection. If desired or necessary, manual intervention (editing of the image net) can be used to improve its fidelity.

WipFrag measures the 2-D net and reconstructs a 3-D distribution using principles of geometric probability (Maerz, 1996a). A "missing fines" correction based on empirical calibrations, can be used, if appropriate. Alternatively, the WipFrag zoom-merge mode allows the combination of results either from several images of the same scale ("merging") which is necessary for reliable estimation of large blocks, or the combination of results from several images at different magnification ("zoom-merging", Morley et. al, 1996) for accurate estimation of fines or for system calibratio n.

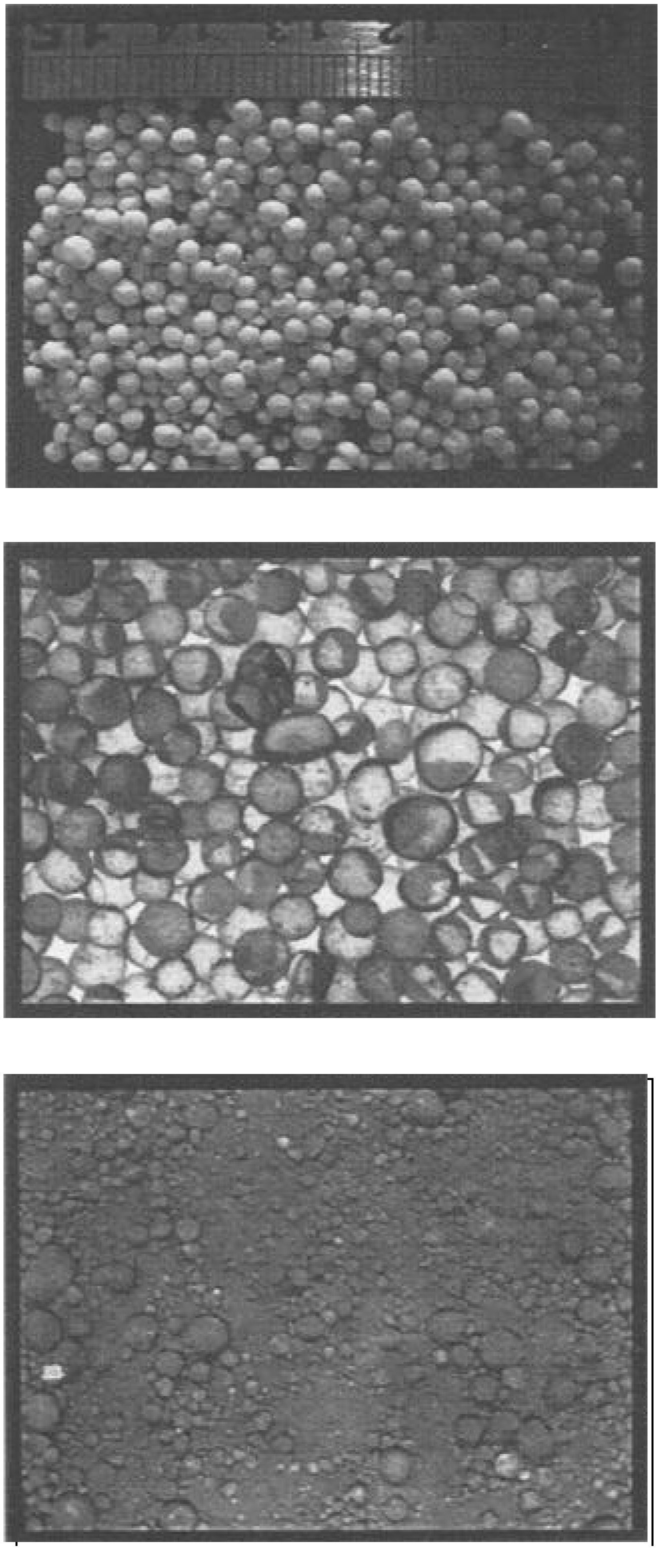


Figure 2. Images of prills, beads, and ore concentrates.

The flexibility of the system allows various types of output according to individual requirements, including cumulative size distribution graphs, histograms, and custom “strip chart” time based graphs to record variations in product quality quickly, over periods of minutes, hours, days or months.

4 IMAGE ACQUISITION

WipFrag is designed mainly for black and white (greytone) images, although it accepts also colored prints or slides. It will accept either analog or digital images.

Analog images supported are RS170, CCIR, NTSC (luminance only), and PAL (luminance only). The WipFrag system comes with an on board video amplifier, and the software supports manual or automatic gain and offset adjustments, to compensate for less than optimum lighting conditions on the original image. There is also a provision for simultaneously connecting multiple video cameras, which are software selectable.

Digital images supported are images of the BMP and TIFF bitmap variety, with resolutions of 640 x 480 x 256 greytones, or 768 x 574 x 256. Other formats can be also be customized.

4.1 Roving Camcorder input

The most popular way of using WipFrag is by taking images with a roving camcorder.

Consumer camcorders are now in widespread use by agents and personnel in the field. Camcorders are relatively inexpensive, and there is almost no limit to the number of images that can be stored on a single inexpensive video tape cassette. The only requirement is that the camcorder be of S-VHS or HI-8 quality or better, with an S-Video out connector to separate the luminance and chrominance portion of the video signal.

Roving camera input is extremely flexible. Operators can move in and around the fragmentation, and adjust their field of view and angle of photography. They can take pictures of the rock piles from various perspectives, selecting representative images and appropriate scales.

To provide an indication of scale, a scaling object must be included in the image. If the operator chooses, to pan and scroll the camera to cover a large rock pile in a sequence of images, the scale object needs to be visible on only one image, provided that the operator does not zoom in or out during the sequence.

Alternatively, if the surface to be measured is not perpendicular to the line of observation, “tilt scaling” can be used, where by placing a scaling object both at the bottom and the top of the image, a correction for this distortion can be made at a later date, by using the rotation correction in the software.

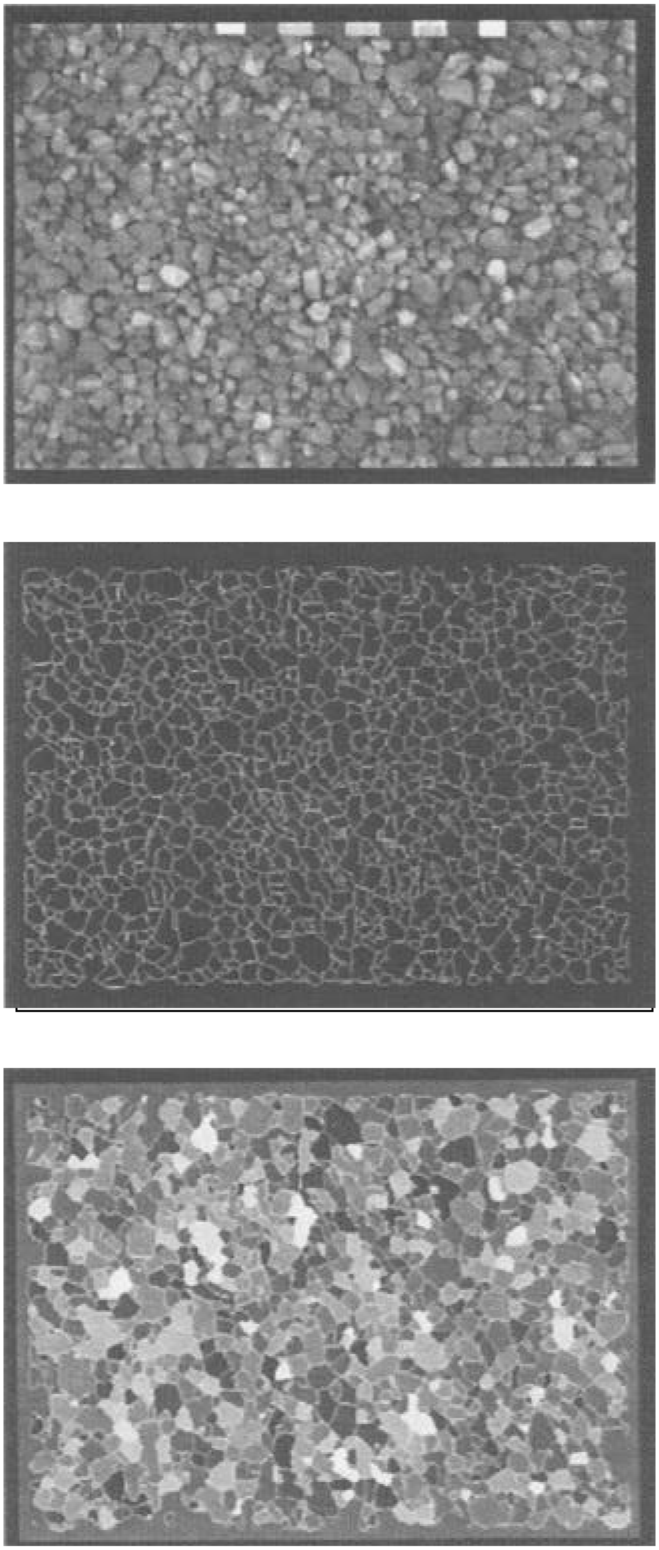


Figure 3. Images of pea gravel (top); net of rock edges (middle); and identified rock fragments (bottom).

4.2 Fixed Camera Input

The WipFrag system can be hardwired to a fixed in place camera, positioned above a drawpoint, conveyor belt, crusher entrance, or dumping station, provided that the processing station is in close proximity to the camera.

The camera may or may not be remotely controlled to pan, scroll, or zoom in or out. If zooming is not done, the scale is fixed, and no scaling object is needed in the image.

If the rock being photographed is in motion, the system may require a strobed camera with a high speed shutter to stop motion. A frame mode camera is also required to synchronize the video fields in the interlaced image.

4.3 Desktop Camera Input

A desktop camera can be used with the WipFrag system. Applications include photographic prints, slides, or negatives, which can be imaged directly using a video camera mounted on a copy stand, using back lighting for slides or negatives.

Another application for a desktop camera is to measure small crushed rock samples, for the purposes of determining empirical calibrations.

4.4 Digital Imaging

Digital images can also be used with the system. Images as described above can be provided on disk, or over a computer network, using a modem, or as an e-mail package in the internet. Images can be compressed if necessary, however the compression must be lossless.

5 IMAGE PROCESSING

Image processing is used to transform the image rock fragments (Figure 3a) into a binary image consisting of a net of block outlines (Figures 3b, 3c).

5.1 Block Identification

The delineation of blocks in WipFrag involves the identification of block edges. This is done in a two stage process.

The first stage uses several conventional image processing techniques, including the use of thresholding and gradient operators. The operators detect the faint shadows between adjacent blocks, and work best on clean images with lightly textured rock surfaces.

The second stage uses a number of reconstruction techniques to further delineate blocks that are only partly outlined during the first stage. These include both knowledge based and arbitrary reconstruction techniques, to complete the net.

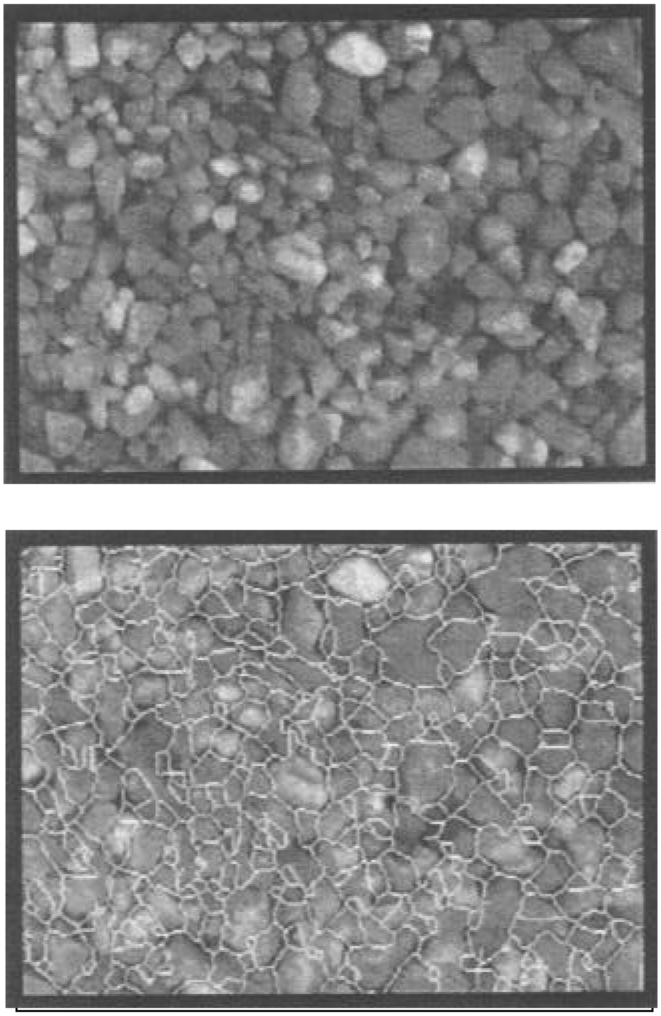


Figure 4. Two times software zoom of image of above figure (top); and net overlay (bottom).

5.2 Edge Detection Variables (EDV)

For each of the image processing stages, parameters called Edge Detection Variables (EDV) are accessible to the user, to optimize the edge detection process. The user has the choice of adjusting individual variables to optimize one stage of the process, or selecting one of nine preset combinations of EDV. These combinations are arranged in sequence to produce more or fewer edges, depending on the nature of the image. Thus selecting more edges will reduce the number of missing edges in a given image, while selecting fewer edges will reduce the number of false edges in that image.

5.3 Editing to improve fidelity of the net

When improved accuracy is required, the fidelity of the net can be increased by manual editing. A set of interactive editing tools, to draw lines and polylines, erase lines, or erase areas, can be used to quickly remove false edges and draw missing edges to complete the net.

The net is normally displayed as an overlay on the original rock images, so the fidelity of the net can at all times be evaluated by the user.

Other editing tools include the following:

1. A software zoom, with software pan and scroll on the enlarged image (Figure 4).

2. A "hide net" toggle to alternately hide and display the net, to allow the user to evaluate the fidelity of the net.

3. A "block ignore" toggle feature, that allows the user to selectively exclude individual blocks for any reason. This allows analysis of two or more phases e.g. ore and waste rock, fines and non-fines, rock and conveyor. This count can be semi-automated according to requirements.

6 MODES OF ANALYSIS

There are three methods of analysis that can be employed when using WipFrag, depending on the relative accuracy required, and the time and resources available.

Since WipFrag uses geometric probability theory to unfold a 3-D distribution (Maerz, 1996), there are sometimes smaller particles "missing" in individual images. These small fragments are not visible either because they are too small to be resolved or are hidden behind larger particles (washed down by rain or dust control watering).

Because the proportion of these "missing fines" is highly variable and difficult to predict, one of the following solutions is used.

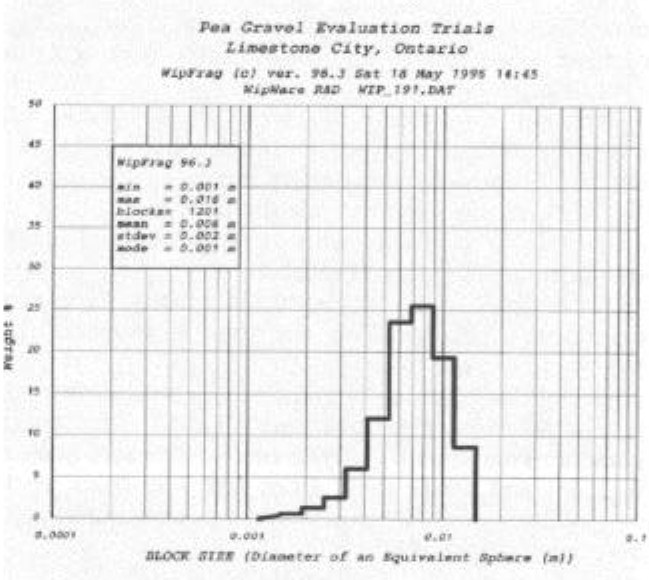
6.1 Basic Method

The basic method provides the quickest answer, and involves taking one or more images and simply analyzing them with no attempt at correction or calibration, although manual editing of the images is an option.

This method is adequate for comparative purposes (e.g. comparing two different blasting agents) and provides good results for narrow (poorly graded) distributions. For wide distributions (well graded) the results are biased toward the coarser sizes.

6.2 Calibrated method

Like the basic method, the empirically calibrated method provides a quick answer while doing production measurements. Again, this involves



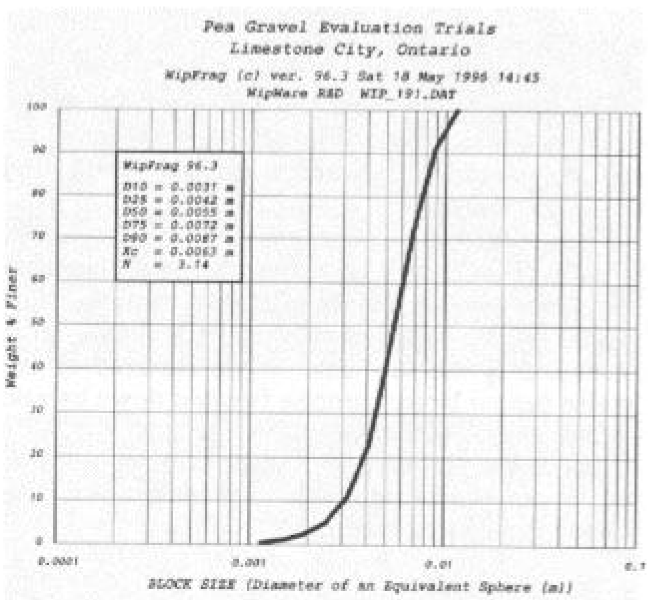


Figure 5. Histogram (top); and cumulative curve (bottom) for the pea gravel distribution.

taking one or more images and analyzing them with or without manual editing. In this method however, the empirically derived Rosin-Ramler (R-R) correction is applied.

The appropriate calibration factor is selected by estimating the slope of the R-R curve of the actual distribution. Calibration factors can be determined in a number of ways, by scaled down or full scale sieving trials by the user under the conditions and rock types appropriate to the measurement, or by detailed analysis with the zoom merge mode described below, or by using the default calibrations provided with WipFrag.

This method is more accurate than the basic solution. Analysis is quick and simple, but calibration factors must be established, prior to the analysis.

6.3 Zoom Merge

Unlike the previous two modes, this solution provides a measurement that is as accurate as possible, and should be employed when a more time consuming analysis can be tolerated.

This method, which provides the most accurate solutions requires multiple images to be analyzed at different scales of observation. It is more time consuming, as it requires additional manual interaction, and more organization of samples and files.

7 IMAGE ANALYSIS

Having identified a net of fragment outlines, WipFrag proceeds with the analysis portion of the measurement. This involves a 2 dimensional measurement on the image, reconstruction of a 3 dimensional distribution and the production of graphical output.

7.1 Measurement of Fragment Areas

In the final operation on the digital image, the block profile areas and shape factors are measured on the outline net of block edges.

To this point in the analysis, all operations are performed sequentially on individual digital images in the computer main memory. At any stage of the analysis, the image or net can be saved on disk for future reference (complete with information such as scaling factors) or printed out on a laser printer to provide a hardcopy for reference.

At this point the list of block profile areas is saved to a small, compact disk file. Subsequent operations can be done immediately, or later, using one or several files at a time, including merging multiple data files into a single analysis.

7.2 Reconstruction from 2-D to 3-D

The initial step in this phase of analysis is to divide the measured two dimensional distribution into 40 size classes or “bins”. The 2-D to 3-D conversions, using principles of geometric probability (Maerz, 1996), are performed on each bin.

Initially the distribution is converted into a 3-D frequency distribution, and then to a weight percent basis. Finally the distribution if converted to a cumulative weight percent distribution.

7.3 Graphical and Other Output

WipFrag provides output in terms of graphs and hard copies of analysis results.

The user has the option of automatically accepting the default graph during the analysis, or selecting several options:

1. Selection of graph type, either a histogram or a cumulative curve, or both (Figure 5).

2. Selection of one or more data files to be plotted, either sequentially, or in a combined merged single graph.

3. Selection of a batch mode, in which sequential graphs are cycled and printed automatically, without user intervention.

4. Selection of an output log file to record the results of each analysis.

5. Selection of value of rock density for the purpose of the calculation of weight.

6. Selection of a calibration value for the purposes of reconstructing the Rosin-Ramler distribution, assuming calibration values have been pre-determined.

All graphs are imprinted with four labels:

1. A user supplied title.

2. A user supplied secondary title,

3. A WipFrag identifier, copyright, and the version number and the date of analysis.

4. The assigned user identifier, and the name of the data file from which the graph was generated.

8. SOURCES OF ERROR

There are potentially three sources of significant error in all vision based granulometry systems; sampling errors, poor edge net fidelity, and missing fines.

8.1 Sampling Errors

Sampling errors, i.e. systematic bias in the process of taking an image of the fragmentation have the potential to be the most serious of all the errors. Such errors result if the camera is pointed at a place in the muck pile where the coarse blocks or zones of fines dominate. This topic is explored in Maerz (1996b).

8.2 Poor Delineation of Fragments

Poor delineation of individual fragments results in erroneous results. Poor delineation arises from a combination of two sources:

1. Poor images, e.g. contrast too low or high, too grainy, lighting inadequate or uneven, or the size of the fragments in the image is too small.

2. Highly textured rock, where shadows and/or coloring on the surface of the rocks are as prominent as the shadows between rock fragments (Figure 6).

Poor delineation of fragments manifests itself in two ways (Eden and Franklin, 1986):

1. A group of fragments are mistakenly grouped together and identified as a single block. This is known as “fusion” and represents a bias toward overestimating the true size.

2. A single fragment is mistakenly divided into two or more individual blocks. This is known as “disintegration” and represents a bias toward underestimating the true size.

Experience with WipFrag has shown that in most cases this problem is not severe. The relative amounts of disintegration and fusion tend to counteract each other and typically the effect on the measures of central tendency such as the mean or D_{50} tends to be slight.

The effect on the measures of variability, such as standard deviation or the slope of the cumulative curve, is however somewhat more pronounced.

The effects of fusion and disintegration can be somewhat reduced by careful selection of the edge detection variables. The effect of fusion and disintegration can be completely eliminated by editing the net. Experience with WipFrag has shown that just a few minutes of editing per image can almost completely negate that problem of fusion and disintegration (Eden and Franklin, 1996).

8.3 Missing Fines

Where the smallest fragments in a distribution are not delineated on the image, either because they are too small relative to the image to be resolved, or they have fallen in and behind larger fragments, there is clearly a bias towards over representing the size of the distribution.

Where the distribution has a relatively narrow size range (well sorted, or poorly graded) this is normally not a problem. However, where the distribution has a relatively wider size range (poorly sorted, or well graded), typically with size differences of more than 1 order of magnitude, missing fines start affecting the measurement results.

WipFrag has the ability to deal with the missing fines problem using either an empirically based calibrations (section 6.2) or by using multiple images taken at different scales of observation (section 6.3).

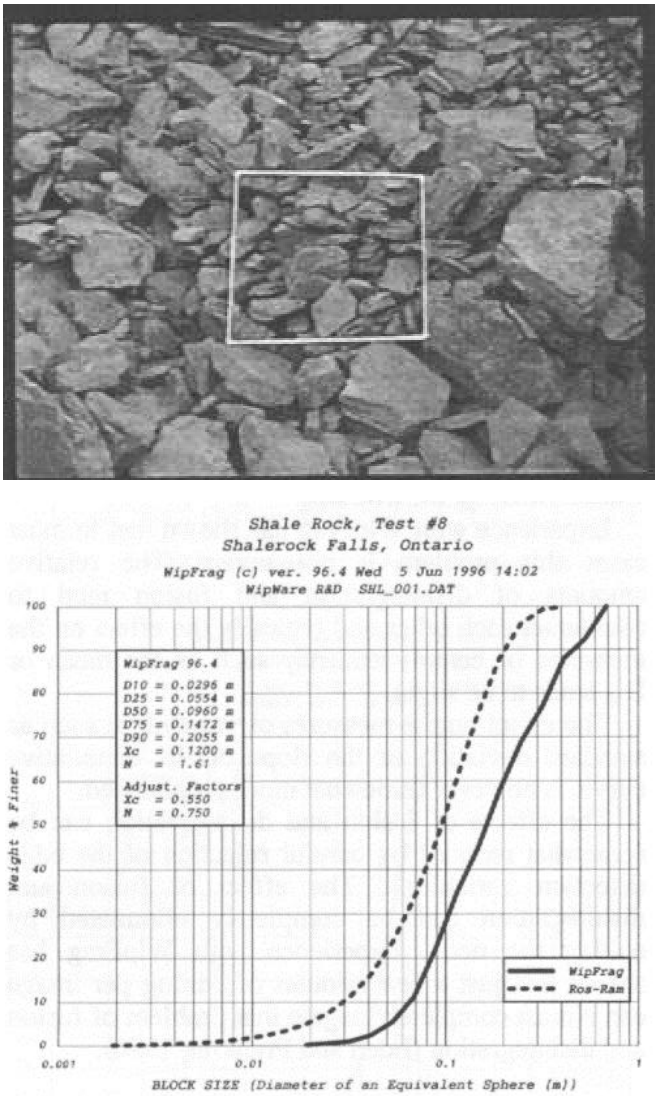


Figure 6. Analysis results for a slabby heavily textured shale rock.

8.4 Other Sources of Error

There are other potential sources of error in the WipFrag analysis. Studies have shown that they are all insignificant when compared with the more significant errors listed above (Maerz, 1990). These include such diverse sources such as:

1. Photographic perspective error (can be reduced by using telephoto photography, and/or by the WipFrag rotation correction (Maerz, 1996b).

2. Operator bias. Studies have shown that slightly different results can be produced by different operators, using different EDV settings, and by the degree of secondary manual editing.

9. VERIFICATION

WipFrag results have been compared with more traditional sieved measurements many times in the last few years. In these comparisons there has been a good correlation between sieved and digital results when the images were of sufficient quality and were statistically representative of the whole sample

9.1 Accuracy and Precision

Accuracy is defined as the difference between the average measured value and the "target" or "true" value. It is usually expressed as the probability of a measurement being within a given percentage of the true value, often the 95% confidence limit.

Precision is a measure of repeatability. A precise method gives consistent values, not necessarily correct ones. If "wrong" they can easily be corrected. Precision is usually measured in terms of the "coefficient of variation" (the standard deviation divided by the mean).

As sieving remains the traditional basis for blast fragmentation measurement, it is selected as the reference standard for determining WipFrag accuracy. WipFrag results may be corrected by calibration to match those obtained by sieving.

Four basic WipFrag features contribute to obtaining precise and accurate results:

1. High fidelity automatic edge detection.

2. Optional manual editing of the net for added fidelity.

3. Empirical calibration option

4. Merging and zoom-merging of data from multiple images.

Error (inaccuracy) is reduced by appropriate sampling and measurement procedures, then any remaining bias is corrected by calibration.

9.2 Laboratory Tests

Analysis of a medium graded crushed limestone aggregate found errors of less than 10% in the D_{50} measure with respect to sieving results, without the benefit of calibration (Maerz, 1990).

Analysis of the pea gravel shown in Figure 3, resulted in an overestimation of the D_{50} parameter by 20% without calibration. With calibration, assuming a Rosin-Ramler n value of 3.0 (highly uniform), resulting D_{50} values within 4% of sieving values.

9.3 USBM Field Trials

Field trials, conducted for the United States Bureau of Mines revealed D_{50} valves were within 2-16% of the screened results for many of the analyses, when adjustments were made for missing fines (Maerz, 1990).

9.4 Noranda Tests

Recent tests were conducted by Noranda to evaluate three different image based granulometry systems (Liu and Tran, 1996). In these tests no calibration or operator intervention was permitted, only automated measurements. WipFrag measurements were found to be the closest to the sieved results.

Afterwards with calibration, the D_{50} values measured by WipFrag came within 2% of sieving results (Rosin-Ramler n value of 1.5, average uniformity).

10. CONCLUSIONS

Image analysis is one of the fastest growing new technologies and indeed a tool of the 90's. It allows operations for the first time to quickly, accurately, and economically measure particle sizes generated by blasting, crushing, grinding, and other forms of mechanical handling. Today's competitive markets force producers to optimize production and minimize costs.

WipFrag is a state of the art image based granulometry system. Its capabilities make it ideal for tracking fragmentation and assisting in blast optimization.

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