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Microcomputer Image Analysis of Rock Fabric

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SYNOPSIS

The behavior of many types of rock is largely dependent on the fabric of the rock mass. Current methods of manually measuring the discontinuity networks in rock masses are slow, tedious and error prone. The alternative is to make automated measurements of rock jointing parameters on digital images of rock faces in mines, tunnels, and surface excavations.

Photoanalysis techniques are being developed to measure various rock fabric parameters. Techniques presented here include the generation of a joint trace map from a photograph, and the measurement of simple statistics on the joint trace map. Methods are also presented for the determination of block size, both in situ and in muck piles. Finally, a method for measuring the roughness on a joint face using a shadow method is presented.

INTRODUCTION

The behavior of many types of rock is largely governed by discontinuities within that rock mass. For example, the strength, deformability, and fluid conductivity of competent rock masses depend more on the nature of the joints and the jointing pattern, than on the nature of the intact rock.

Existing methods of characterizing joints and joint systems are usually based on manual measurements and simplistic concepts (CANMET, 1977; ISRM, 1978; Barton et al., 1974). Measurements made by tape and compass are slow and laborious, and seldom provide sufficient data for valid statistical representation. In many cases there is a physical risk involved when manually obtaining such data. In addition, many of the physical parameters of rock fabric, such as persistence, are poorly defined. Numerical analysis of jointed media such as keyblock methods (Goodman and Shi, 1985) and distinct element methods (Cundall, 1971) are now more sophisticated than the data on which they are based.

An alternate method of characterizing the jointing is to use digital photoanalysis. Automatic measurements made on digital images of rock faces are quicker, safer, less expensive, and more comprehensive than manual measurements. In addition, the image retains a permanent record; it can be reanalyzed later.

The photoanalytical techniques have been introduced in previous papers (Franklin and Maerz, 1986, Franklin and Maerz, 1987). The techniques involve photographing, digitizing, and enhancing an image of a rock face. The photography is done using either 35 mm black and white still photography or 8 mm video tape. Depending on the type of analysis and the complexity of the image, it is either automatically digitized into a raster array using a video camera and digitizing board, or manually digitized using an X-Y digitizing board. Measurements are then made on the digital image.

In this paper four different types of analysis are described.

THE JOINT TRACE MAP AND JOINTING STATISTICS

Basic parameters of jointing, such as spacing, trace length, and orientation are clearly important parameters in terms of rock stability and groundwater flow. The more data that can be gathered on these parameters, the better subsequent analysis will be.

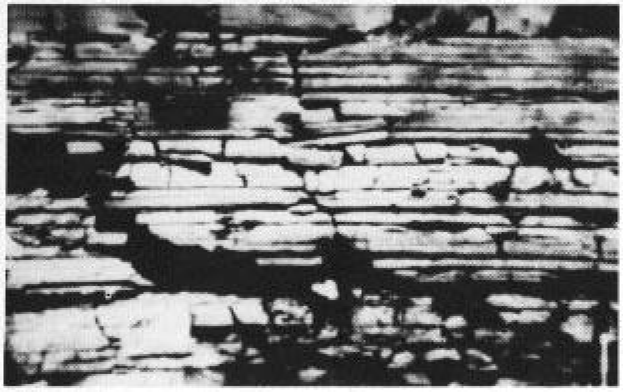

Fig. 1. Digital greytone image of a rock face.

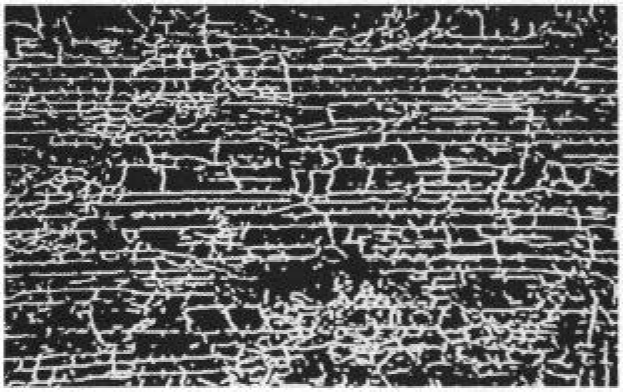

Fig. 2. Binary image of joint traces on a rock face.

Current methods of assessing these parameters consist of manual measurements using tape and compass. These methods are inadequate because they involve substantial costs in terms of man-hours, return insufficient amounts of data, and are restricted to the accessible parts of the rock face. In addition, there is often physical danger involved in obtaining these measurements.

These parameters can instead be measured by computer on a suitable image of a rock face, using digital image enhancement and analysis (Fabbri, 1984). However, in order to analyze any image by computer, the image must first be captured and coded into a digital database. In order to make the digital measurements, the image must be reduced to a binary image, where, for example, the joint traces are represented by white lines on the black background. This binary image is known as a joint trace map.

Photographic image acquisition and enhancement

The image of a rock face is acquired by taking a standard analog television signal (eg. the RS-170 standard), and digitizing it using a video digitizing circuit board plugged into an IBM AT microcomputer. The RS-170 signal can be taken from a video camera focused on the rock face, from a video camera focused on a photograph of the rock face, or from a video tape recording. The analog frame is split into 480 lines of 512 pixels (picture elements) per line. The intensity (brightness) of the image at each pixel is recorded as one of 256 grey tones (Fig. 1).

Image enhancement refers to the process of manipulating and transforming the digital image to bring out or "enhance" certain features such as dark areas, light areas, linear features etc. For the purposes of analyzing joints on images of rock faces, it is the network of linear features on the greytone image which need to be identified or enhanced (Fig. 2). Many techniques to enhance these features are readily available and can be easily applied (Castleman, 1979). This can be done in a number of ways:

If the joint traces are extremely well defined, i.e. such as lighter lines on a darker background, or darker lines on a lighter background, a binary image can be created using thresholding. Thresholding is the process of mapping pixels below a given intensity to black, and those above to white.

A second method is to use a convolution filter such as a gradient operator. This results in a binary image of lines produced where there is the greatest rate of change of greytone intensity.

A much more promising method of joint detection is to identify "peaks" or "valleys" in intensity (Karpala, 1981). This is done by convolving the image with a low pass filter (eg. a Gaussian filter), taking the first difference of the image, and identifying the points of inflection (bottoms of the valleys) by detecting zero crossings. An example is shown in Fig. 2.

Post processing to further enhance the binary joint trace image may be needed to filter out spurious lines and other noise. The image may need to be skelletonized or converted to a vector database using a raster to vector conversion algorithm.

Basic jointing measurements

From the binary joint trace image, a number of techniques are available to extract the required measurements directly. Trace lengths and orientations can be found using "line walking" methods, in which an algorithm is used to follow the trace pixel by pixel and to record lengths and average orientations. Spacing of the traces can be found using transects at given angles to the trace, in which the algorithm counts the number of intersections per unit length of transect.

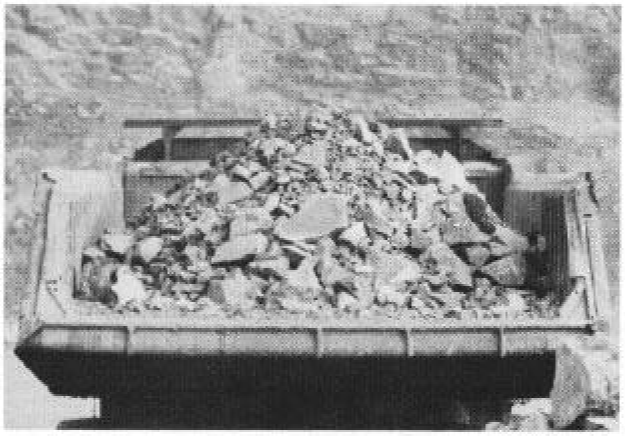

Fig. 3. Broken rock in the haulage trucks.

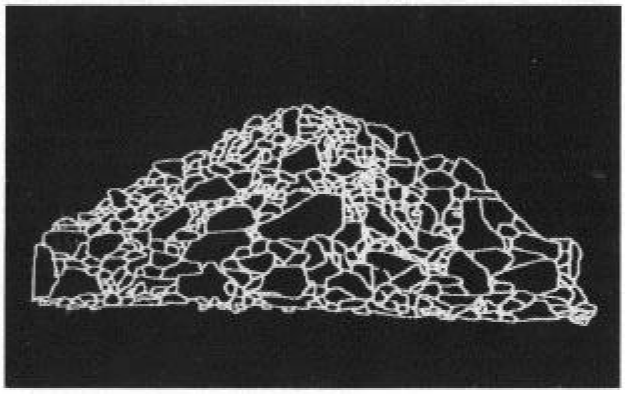

Fig. 4. Digital image of the block profiles.

BLOCK SIZE DETERMINATION OF BLAST FRAGMENTATION

Fragmentation is an important measure of the efficiency of a blast. Smaller fragment sizes result in lower loading, hauling, and crushing costs, but require more drilling and explosives. If fragmentation could be measured quickly, the blast design could be adjusted for optimum efficiency.

Currently, inadequate methods, if any, are being used to estimate block size distributions. Boulder counting and visual estimates (Grant and Dutton, 1983) are respectively time consuming and inaccurate. Sieving (Dick et. al., 1973) is prohibitively expensive for full scale blasts. Predictions of block sizes from blasting parameters and rock structure (Just and Henderson, 1971) do not actually measure the fragmentation. Existing photographic methods (Aimone and Dowding, 1983) simply measure the completely visible fragments on the surface of a pile.

A photoanalytical method can be used to measure block size distributions of blast fragmentation (Maerz et. al. 1987a, 1987b). The method has been developed to photograph, digitize, and measure the surface of a pile of broken, overlapped rock, and to reconstruct a size distribution.

Photographic sampling

In order to get the most accurate measurement of block size possible, the blocks in the photograph must be in some way representative of the blocks in the muck pile. In addition, the photograph must be taken without disrupting production.

Photographing the surface of the muckpile was considered, but rejected, as the surface may not be representative of the entire muck pile. Photographing a vertical cut through the muck pile was also considered, but rejected, because it would cause production delays.

The sampling strategy adopted consisted of photographing the fragmentation in the backs of the haulage trucks. A loader was used to lift a vertical section from a known location in the muckpile, without disrupting production (Fig. 3).

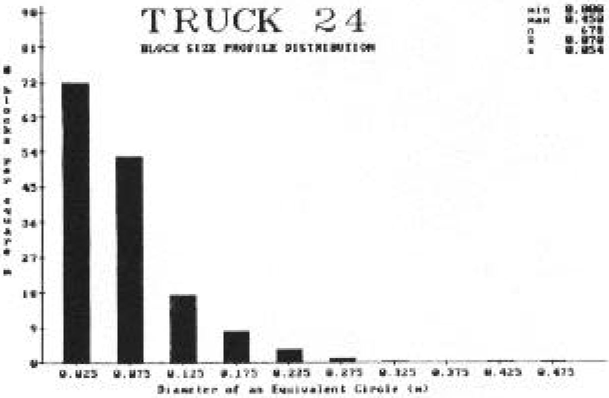

Fig. 5. Block size profile distribution.

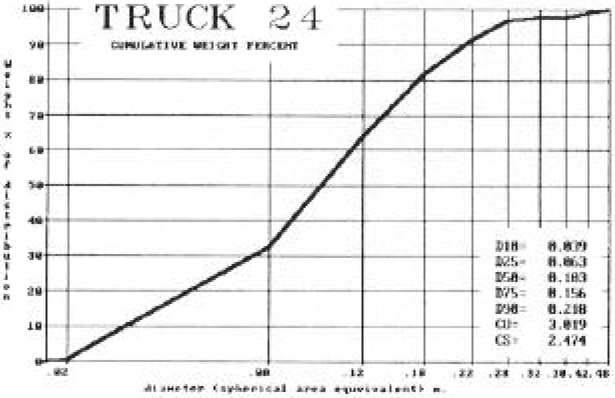

Fig. 6. Cumulative weight per cent distribution.

Digitization and measurement of block areas

Ideally, the photographic image would at this point be digitized directly. However, the problem of uniquely and correctly identifying individual blocks is as of yet too complicated for current image analysis software. Instead, the block shapes are manually traced on to a mylar overlay, and the line trace image is then digitized (Fig. 4).

The profile areas of the digitized blocks are then measured, expressed in terms of area-equivalent diameters, put into ten classes of equal class width, and plotted in a histogram (Fig. 5).

Reconstructing the true block size distribution

The profile area distribution, although useful for purposes of comparison, is not equivalent to the true size distribution. To reconstruct the true distribution, three elements must be considered:

Overlap of some of the fragments.

Some missing fine fragments.

Anisotropic stacking of platy blocks, if present.

The following unfolding equation, derived from geometric probabilities is applied:

$$N_v(d) = \frac{1}{d\ f(d)} N_a(d). \qquad \text{(Maerz et. al, 1987)}$$

where N_v is the number of blocks per unit volume, N_a is the number of profiles per unit volume, and d is the diameter class. f is an empirical coefficient of proportionality derived for each class, from model studies of crushed rock distributions. The value of f approaches unity for all but the smallest size classes. The result of applying this unfolding equation is the reconstructed true size distribution.

Finally, the distribution is converted from the frequency histogram into a cumulative weight distribution, such as is used for aggregate and soil size distributions (Fig. 6).

Summary

The photoanalysis technique for measuring size distributions of blast fragmentation, for the first time provides a tool for rapid and comprehensive evaluation of blasting designs. For minimal investment in time and effort, the size distributions in a muck pile can now be quantified.

IN SITU BLOCK SIZE DETERMINATION

The size of blocks in a discontinuous rock mass affect both the stability behavior of the rock mass and the ease of excavation. In underground openings, the larger the block size, the more stable an unsupported roof will be. In quarries, the larger the block size, the more explosive will be needed to comminute the blocks to specified size distributions.

Current methods of determining block sizes involve measuring the spacing of three or more joint sets and inferring the block size. Typical methods make use of block size index (I_b) and volumetric joint count (J_v) (ISRM, 1978). These methods however do not quantify true block size.

Beyer and Rolofs (1981) present a method of determining block size distributions from linear measurements on a rock face. These type of stereological methods of "unfolding" block size distributions, based on geometric probabilities, have been used for some time by biologists and metallographers to determine particle size distributions from microscopic thin sections and polished sections. They make use of geometric probabilities to extrapolate two dimensional measurements to three dimensional distributions.

The Beyer and Rolofs method makes use of a grid of line scans measuring number of blocks per unit length of line scan. The measurements are made manually on the rock face. This makes the method both tedious and time consuming, and is restricted to the accessible parts of the rock face. Additionally, the method has not been independently verified in any way.

A photoanalytical method can be used to automatically measure the number of blocks per unit length of line, or the number of blocks per unit area, on photographs of a rock face. In addition, a numerical simulation of a discontinuous rock mass is being used to verify the unfolding methods.

Photographing and measuring block areas

The image required for measuring in situ block sizes is the same image used for creating the joint map. The image is modified to produce a continuous network of polygons by extending existing joint traces. Black areas can be then measured as in the case of the blast fragmentation method.

Reconstructing the true block size distribution

Reconstructing the true block size distribution requires extrapolating the two dimensional size measurements into three. Many algorithms, based on geometric probabilities, are available to do this. Some of these methods are given by DeHoff and Rhines, 1968, Underwood, 1970, and Weibel, 1979 and 1980.

Verification of the method

Since none of these theoretical methods of reconstructing true size distributions can be physically verified, a computer simulation has been developed for this purpose. The computer simulates a rock mass of known jointing parameters, and outputs a simulated rock face cut at random in that rock mass. This cut manifests the equivalent of a joint trace map.

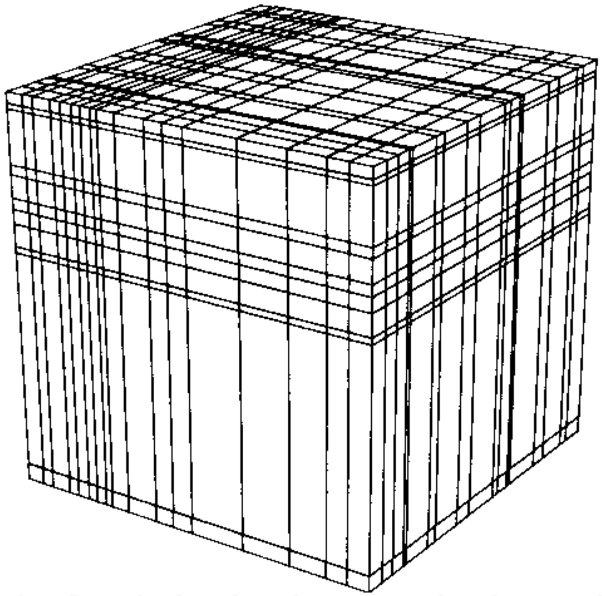

Fig. 7. Simulated rock mass cut by three orthogonal joint sets.

The simulation uses Monte Carlo methods to generate three or more sets of joints intersecting a cubic volume (Fig. 7). The intersecting joints divide the cube into several thousand unique blocks. The volume of each of these blocks is measured to determine the true block size distribution of the assemblage of blocks.

The cube is then cut by an arbitrary plane. The individual blocks are represented by polygons on the cut plane (Fig. 8). Two dimensional size measurements are made, and the reconstructing algorithm is applied. The reconstructed block size can then be compared to the actual (measured) block size.

Summary

This photoanalytical technique, will for the first time allow an accurate quantification of block size in the rock mass from photographs of a rock face. In addition to being helpful for stability analyses, the method will be useful in blasting design.

JOINT ROUGHNESS MEASUREMENTS

The roughness of joint surfaces fundamentally affect the deformability and fluid conductivity of the rock mass. In general, a rough joint surface has greater shearing resistance and a potentially greater dilatency. As well, a rough joint surface tends to have a lower hydraulic conductivity. If roughness can be characterized quickly and accurately, then methods exist to predict shear strength (Barton and Choubey, 1977) and conductivity (Barton et. al., 1985).

Existing methods for sampling joint roughness include profilometry (Weissbach, 1978), compass and disc-clinometry (Feckers and Rengers, 1971), and photogrammetry (Ross-Brown, 1973). These methods are both tedious and complicated.

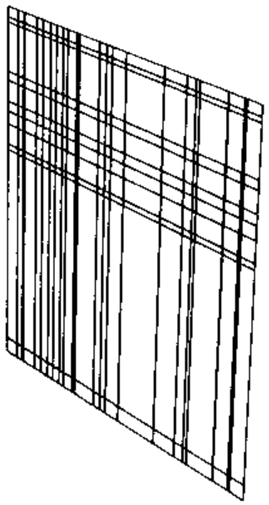

Fig. 8. Arbitrary cut through the simulated rock mass.

A photoanalytical technique can be used to measure the roughness of a straight edge shadow cast onto a joint surface. A simple trigonometric transformation can be used to convert the shadow into an approximation of the joint profile.

Photographic sampling

The straight edge shadow method is based on the fact that the intersection of plane of light and the joint plane will be a straight line if the joint plane is perfectly flat, and an undulating line if the joint plane is rough. The undulation of the edge of the shadow corresponds to the roughness.

In practice, a plane of light is created by shining a light at low angle past a straight edge to cast a shadow on the joint face. The edge of the resulting shadow follows the topography of the joint surface. The photograph is then taken normal to the joint surface. An example is shown in Fig. 9, where the straight edge shadow method is demonstrated using corrugated cardboard. (Note that the edge of the shadow mimics the profile of the cardboard.)

The incident angle of light is calculated by measuring the length of a shadow cast by a post of known height onto a circular disc. This device is referred to as a "sundial" (Fig. 10).

Enhancement and Analysis of the roughness trace

Image processing techniques are applied to the digital image to enhance the edge of the shadow. Two enhancement procedures are performed: Aa threshold operator is applied to produce a binary image (Fig. 11) from which the edge of the shadow is isolated (Fig. 12). The resulting roughness trace is then converted into a string of cartesian coordinates using a raster to vector conversion algorithm. The trace is then transformed to produce a representation of the actual joint profile (Fig. 13).

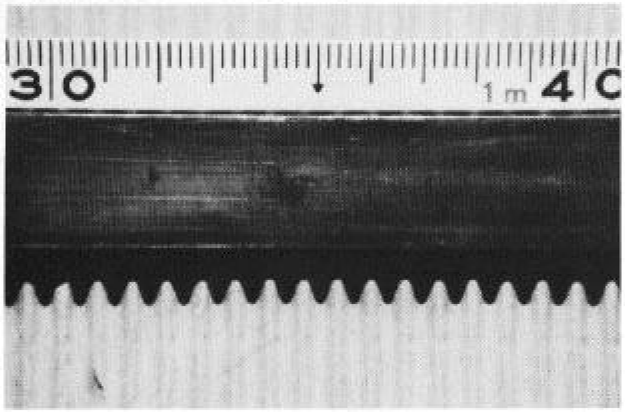

Fig. 9. Roughness measurement on a sheet of corrugated cardboard exhibiting roughness in one direction.

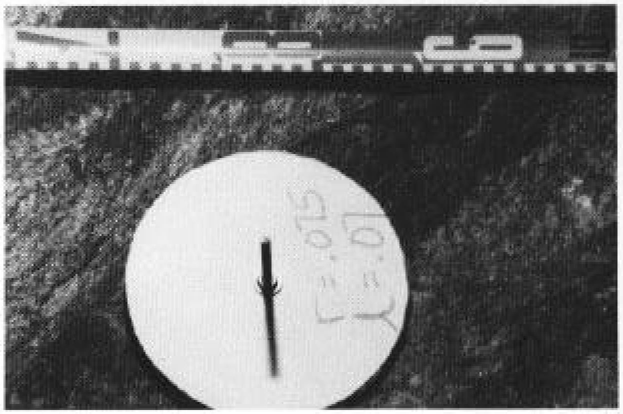

Fig. 10. Demonstration of the straight edge shadow method, including sundial" to measure incident angle of light.

The techniques employed characterize roughness in terms of the root mean square of the first derivative (Z_2), the roughness profile index (R_p), defined as the ratio of the length of the trace to its length projected on the mean plane, and the micro average i angle or the average inclination angle of the trace at the smallest scale of resolution for a given image. Each of these is correlated with JRC (joint roughness coefficient) by comparison with a digitized version of Barton's ten roughness profiles (Barton and Choubey, 1977). This has previously been demonstrated by Tse and Cruden (1979). Any one of the resulting regression equations can be used to obtain an estimate of JRC. This estimate can then be used to predict shear strength given the empirical model previously developed by Barton and Choubey (1977), provided supplementary information such as JCS (joint compressive strength) or UCS (unconfined compressive strength) of the intact rock is known.

Summary

Joint surface roughness can be determined quickly and accurately using the straight edge shadow method. This method uses simple, inexpensive equipment and allows for a large number of measurements to be made rapidly. From the measurements, the joint roughness can be quantified and related to shear strength.

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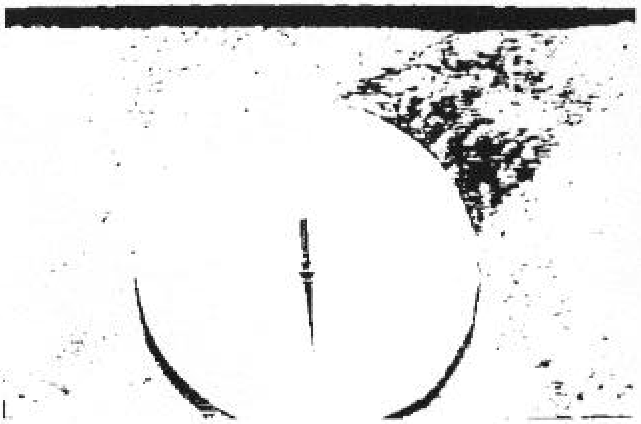

Fig. 11. Binary image of shadow on the joint surface.

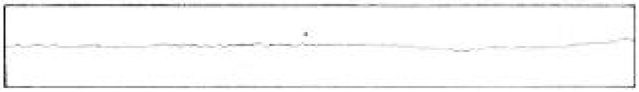

Fig. 12. Isolated edge of the shadow.

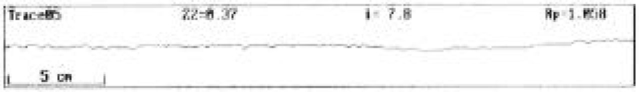

Fig. 13. Final joint roughness profile.

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