Blast overbreak measurement by light sectioning

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Summary

In this new method for measuring the cross-section of tunnels and other excavations, the opening is outlined by a plane of light projected from a conical mirror. The image is recorded on videotape, enhanced, then measured by microcomputer. The measured profile is compared automatically with the specified profile to give values for overbreak and underbreak.

Trials in Mexican tunnels and at an underground mine in Canada have evaluated the technique in relation to traditional mechanical, photographic, and surveying alternatives. Results indicate that the light sectioning method requires less than a minute per profile and no surveying skills. Costs are low, and the measurements are accurate to within a centimetre or two. Using the same photoanalysis technique and software, rock quality can be measured at the same time and place as overbreak, which helps the engineer to decide whether overbreak is caused by geological conditions or by deficiencies in blasting.

Keywords: Rock tunnels; rock blasting; tunnel overbreak; photoanalysis.

Introduction

Definintions of blast damage

Overbreak is defined as the unwanted removal of rock beyond a specified maximum excavation perimeter (called the 'B' line in tunnelling), whereas underbreak is unwanted rock remaining within a specified minimum excavation perimeter (the 'A' line). Both add to the cost and duration of work: overbreak often has to be replaced by concrete or shotcrete, and can also lead to rock instability; underbreak requires secondary excavation.

Overbreak and underbreak can be reduced or eliminated by careful control of blasting parameters such as the size, spacing and alignment of the holes, the charge distribution, and the delay pattern.

Need for measurements

An important element of blasting control is to be able to measure the excavated profile quickly, safely, and accurately, and thereby to diagnose and correct blasting problems.

A reduction in blast-induced damage can in turn lead to fewer rock falls and improved safety; less rock to be removed and concrete to be poured (Proctor, *et al.*, 1946; Muller, 1959; Kanoh and Ohtsuka, 1983); a thinner relaxed or plastic zone, calling for less bolting and concreting (Holmberg, 1979; Sakurai *et al.*, 1985); reduced hydraulic conductivity in the fractured zone and less water inflow (Kelsall *et al.*, 1984); and a significant increase in rates of advance and a reduction in costs for explosives and drilling (Hamrin, 1974; Hagan, 1984; Hulkkonen, 1987).

Tunnel profiling methods as described in this paper can be used to measure not only volume of overbreak and underbreak, but also volume of concrete needed to line an opening to a specified concrete line; volume of applied and rebounded shotcrete; volume of backfill needed to fill a mine stope; and even the time-dependent convergence of openings, if the method is sensitive and the deformations are sufficiently large.

In addition and most importantly, they can help to differentiate between geological causes of overbreak (such as intense or adversely oriented jointing) and causes related to inadequate blast design or execution (such as inaccurate drilling) – questions which are fundamental to resolving contractual disputes related to 'changed ground conditions'.

Traditional methods of measurement

As long ago as 1886 the 4.5 m circular New Croton Aqueduct in New York was measured mechanically with the Sunflower Cross-sectioner (Durham, 1913). This consisted of a telescopic pole on pivoting disc, that was extended to measure the distance to the tunnel wall at fixed angles. The area of the section was determined with a planimeter on a paper plot.

Various tunnellers have used a photographic method in which a thin sheet of light is projected radially onto the walls, and overbreak is calculated by manual measurements on photographs (Koppenwallner, 1959; Fellows, 1976; Thompson *et al.*, 1979; Legge *et al.*, 1981).

A commercial device, used in Switzerland, is described by Hertelendy (1983). This is an automated instrument which uses optical triangulation by a light beam and photodiodes to measure distances to the tunnel wall.

Measurements by laser have led to improved accuracy. Celio and Matthias (1983) describe trilateration from the measured lengths between reflecting targets. Breytenbach (1985) used a pulsating laser, measuring travel time, and Hagedorn (1986) describes a commercially available profilometer, a pulse laser mounted on a theodolite with digital storage capabilities.

The relative merits of the methods can be evaluated according to the following criteria:

— Simplicity and low cost, taking into account purchase, operation and maintenance of equipment and the need or otherwise for skilled personnel;
— Minimal interference with tunnelling operations and delays to production;
— Reliability under a range of conditions of temperature, humidity and dust;
— Accuracy and versatility when applied to different shapes and sizes of tunnels, shafts, inclines, and caverns;
Speed, and ability to give immediate feedback to allow modifications to the next round of blasting;
— Clarity of graphical and numerical output.

Manual survey methods are usually slow, labour-intensive, and costly. Still photography also tends to be slow and inconvenient because of the processing time, and results are seldom available soon enough to be useful for making modifications to blasting. Manual analysis of the photographs is often inaccurate and subjective.

Triangulating laser methods require reflectors to be mounted on the tunnel wall at each point to be surveyed, which is time consuming.

Pulse laser measurements, which rely on the reflectance of the rock surface, can be affected by changes in the refractive index of air (caused by dust and humidity), and by dust and oil on the rock surface, and in practice can be used only in tunnels of a radius of 5 m or greater (Hon *et al.*, 1985; Breytenbach, 1985). The capital costs also tend to be high.

The method of light sectioning

Measuring principle

The method developed by the authors uses a conical mirror to project a plane of light on to the walls, roof, and floor of a tunnel or cavern, thus defining a cross-sectional profile of the opening (Figs 1 and 2). The image is recorded by video camera. A perfectly cylindrical tunnel gives a perfectly circular profile. Overbreak or underbreak make the circle bulge outward or inward.

Equipment specification

The field-portable illumination equipment (Fig. 1) contains a conical mirror, a high intensity light source, and an illuminated reference scale and pendulum. This is supplemented in the tunnel by a highly sensitive video camera, and in the site office, by an image analysing computer.

For a light source, the authors use a Maglite ML-6 focusable flashlight with krypton bulb, which produces 16 000 candlepower. The reflector is a 90° machined steel cone with an electroplated chrome finish. The light source and reflector are mounted on an aluminium frame to preserve the alignment between components. The light is focused to produce a line as narrow and intense as possible at the tunnel wall, 10 to 20 mm thick for a small tunnel.

A small reference lamp shows the cone position. Two lamps 1 m apart on a swinging pendulum arm define both the scale and the vertical (Fig. 2).

If the tunnel uses a laser alignment system, the remote laser can take the place of a flashlight source. The flashlight in the portable illuminator apparatus is replaced by a tube, which ensures firstly that the cone mirror is centred, and secondly that it is aligned in the direction of the beam so that the reflected light gives a true cross-section.

The video camera is a Panasonic Omnivision PV-S350-K with NTSC video output. The storage medium is S-VHS video tape with 400 lines of resolution. Minimum illumination is 1 lux.

The image analysing computer is an IBM PC-compatible 80386 computer, with PCVISIONplus frame grabber/image buffer, resolution 512 × 480 × 256.
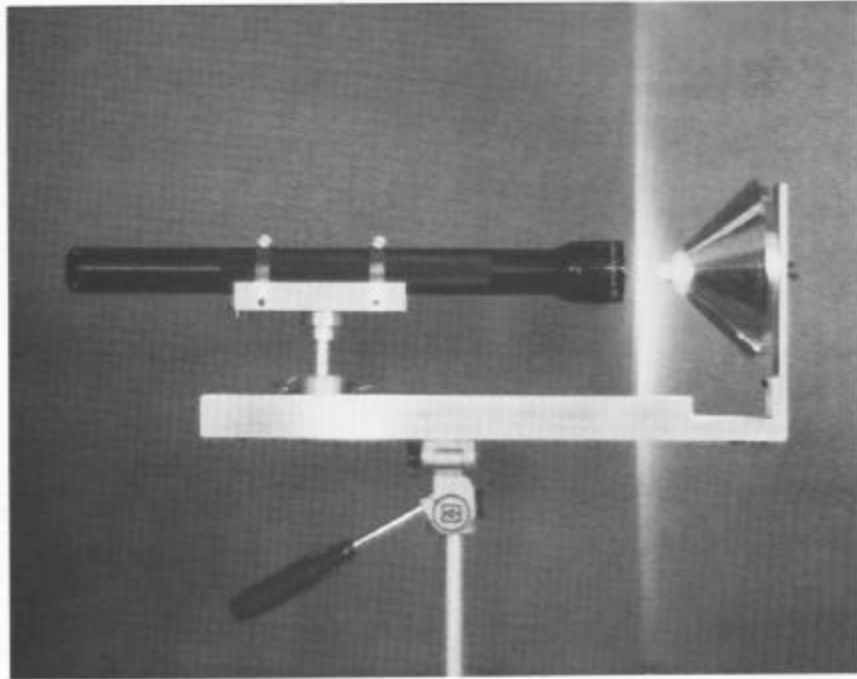
Fig. 1. Illumination apparatus with light source and cone mirror, projecting a plane of light onto the rock. The flashlight source can be replaced by an alignment tube for use with a remote tunnel laser

Measurement procedure

Two operators are needed, one to hold and position the illuminator, and one to take the video image.

The illuminator is placed at a known chainage and aligned with the tunnel axis until the light appears as a continuous ring on the tunnel wall. For purposes of later calculations, the tunnel centreline is known from a pre-surveyed mark or an alignment laser beam in the field of view. Centrality of the apparatus with respect to the cross-section is therefore immaterial except that a central location gives a more uniform illumination.

The scene is recorded by video camera positioned a short distance back along the tunnel. The separation distance between camera and light source is selected so that the tunnel cross-section fills the field of view, thus giving the best possible resolution. The camera is oriented so that the scale arm pendulum appears vertical in the video image.

Profiles are taken at intervals, for example every metre along the tunnel, depending on requirements. Chainages are identified either visually on the videotape, or audibly on the accompanying sound track.
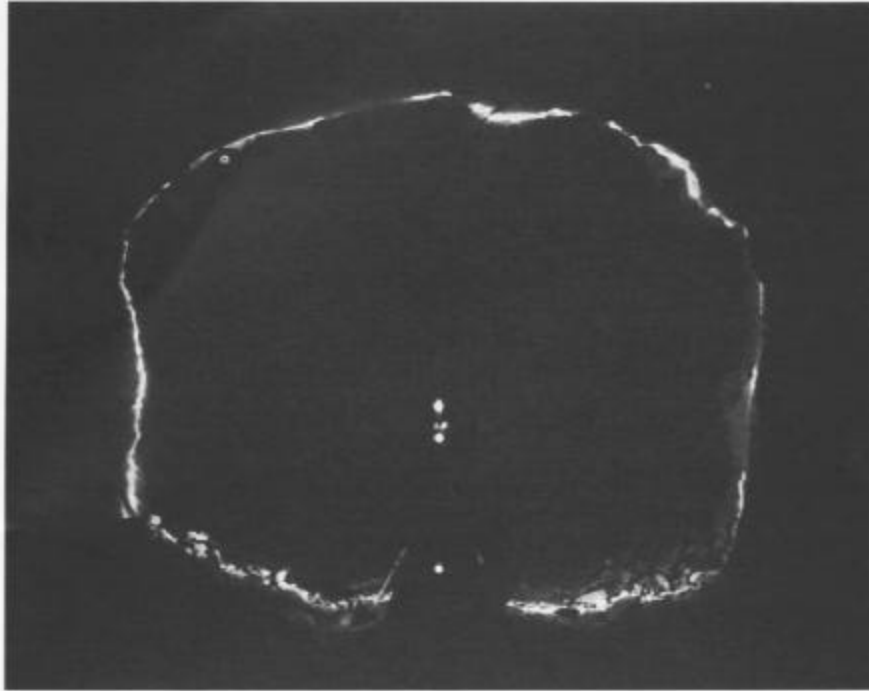
Fig. 2. Light section profile of an underground opening. Note the three reference lamps in a vertical line

Analysis procedure

Image analysis is best performed in the site office, immediately after completing the tunnel survey.

The scale of the image is first calibrated by matching the observed length of the scale arm pendulum to its actual length. If necessary, the image is then rotated into the vertical position.

The image is composed of 512 by 480 pixels, each with one of 256 grey tones. It is converted to binary by a 'thresholding' operation in which the threshold level is adjusted until the light ring defining the tunnel profile becomes white on a black background. The profile line is then thinned to the width of a single pixel by a skeletonization algorithm, and missing line sections are interpolated to give a complete profile.

The observed profile is superimposed on the design profile, indicated by 'A' and 'B' lines. The software permits various options for tunnel shape and size. Areas in the tunnel outside the 'B' line, and those inside the 'A' line are highlighted in colour on the screen, and are calculated and printed alongside the graphical output (Fig. 3). Processing time for each image is about 2 min per section.
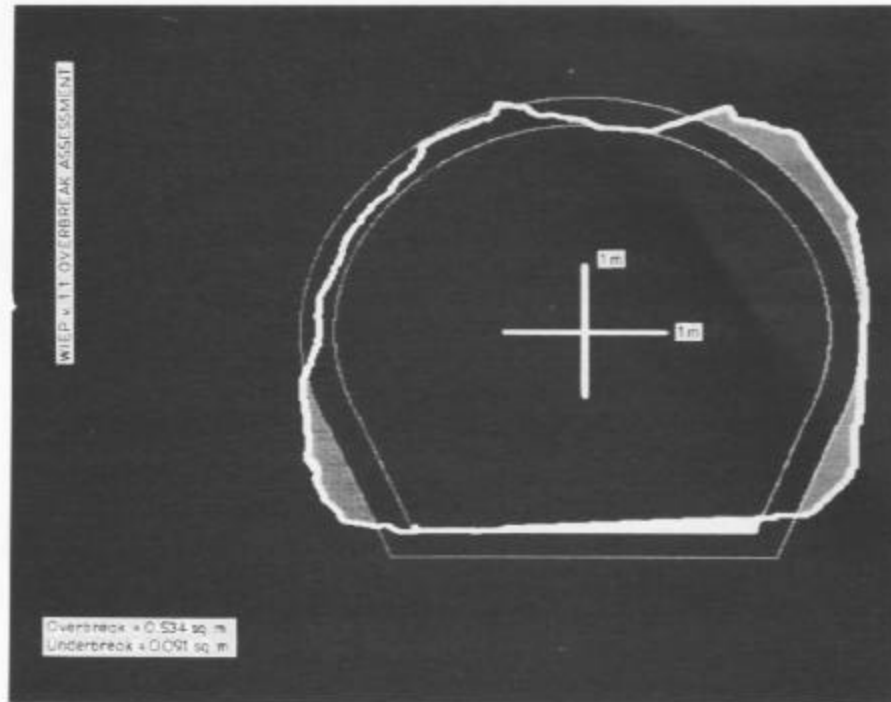
Fig. 3. Typical computer-generated tunnel profile with superimposed design cross-section and zones of overbreak

Trials of the method

Mexican tunnels

The method was evaluated in August 1988 at the Trigomil Irrigation Project 150 km southwest of Guadalajara, Mexico, in a horseshoe-shaped tunnel in granite. The cross-section was 9.2 m^2, and the diameter about 3.5 m. Profiles were measured using the light sectioning method every 2 m along the tunnel, over a length of 50 m. They were analysed for overbreak and underbreak relative to the 'A' and 'B' lines as specified in the design.

The results were compared with the tunnel cross-section surveyed by theodolite: 28 points were measured around the perimeter, lines were interpolated between these points, and volumes were calculated by planimeter.

In a similar trial but a larger excavation, the method was tested in August 1988 at the Agua Prieta Hydroelectric Project on the outskirts of Guadalajara, Mexico. The tunnel, in rhyolite and ignimbrite, was horseshoe-shaped with a cross-section of 32.8 m^2 and a diameter of 6.5 m. Profiles were measured by light sectioning at 2 m intervals along a 16 m length of tunnel.

For the smaller diameter Trigomil tunnel which was in reflective rock, the profiles were good; about 85% being clearly visible in the image. For the larger diameter Agua Prieta

tunnel in rock of lower reflectivity, only about 70% of the profile was visible in the image, although the remainder could be interpolated with little difficulty.

The overbreak and underbreak quantities measured by photoanalysis and by conventional surveying proved to be similar, but the light sectioning method reproduced the tunnel shape more quickly and more precisely, with fewer and smaller linear interpolations.

Ansil Mine, Quebec, Canada

The light sectioning method was also tested in Noranda's Ansil Mine in Canada, in an access drift in andesite with a typical excavation diameter of 4.6 m. In this case, volume of excavation rather than of overbreak was of interest. For comparison, the profile of the drift was measured manually at 16 points, and the cross sectional area was calculated by graphical methods. The results of light profile and conventional surveys differed by only 3%, and the light profile measurement is considered the more reliable.

Evaluation

The method of light sectioning gives fast measurements with little or no delay to tunnelling or mining operations. Less than a minute is required at each measured profile. Costs are low, and the measurements require no surveying or other skills. The method appears to give an accuracy comparable to or better than that of conventional surveying, with the added benefit of instantaneous graphical and numerical output.

A particular advantage is the ease with which overbreak can be related to its causes, either to variations in rock mass quality, or to blasting defects such as inaccurate perimeter drilling. Rock quality (intensity and direction of jointing) can be measured using the same photoanalysis equipment and software as used for measurement of overbreak (Franklin and Maerz, 1987; Franklin *et al.*, 1988; Franklin and Dusseaut, 1989). The results of blasting are compared directly with the quality of the rock, measured on the same image.

With the present relatively modest light intensity, the method works best in small to moderate sized tunnels with reflective walls. In larger tunnels with dark walls, the image becomes progressively more difficult to analyse. These limitations can be overcome by increasing the light intensity, such as by use of laser light. An alternative is to employ a more sensitive video camera.

The method has yet to be evaluated in shafts, steep inclines, and large caverns, where problems of limited access and irregular cavern geometries remain to be addressed. Very large openings such as mine stopes and underground hydroelectric caverns can be measured using still photography with long exposure times, although this is to be avoided because of delays while waiting for film to be processed.

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