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BLASTING AND VIBRATION CONTROL IN BRITISH OPENCAST COAL MINING

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Introduction

A short introduction to opencast blasting as carried out in the UK is followed by discussion of the nature of the nuisance that may be caused when blasting takes place and the procedures that can be taken to minimize these effects.

The methods that have been used to monitor and predict the ground vibrations are traced and the new range of microprocessor based vibration monitors now available on the market are introduced together with illustrations as to how these can aid the site based prediction of the effects of blasting.

As many excellent works exist on the design of blasting patterns, the choice and use of explosive and drilling techniques, these subjects will only be referred to where opencast practice varies from that normally encountered.

Opencast Blasting

Generalizations about an operation as varied as blasting in opencast coal mines are inevitably subjective but a few comments may be helpful.

(a) It is the overlying waste rock that is blasted, rarely does the coal itself need blasting prior to loading away. Hence the entire cost of the blasting operation has to be justified by the increased production and reduced maintenance costs of the earthmoving plant.

(b) The factors that determine the volume and degree of blasting, even the need for blasting are subjective, so blasting practice varies from site to site, even person to person.

(c) The degree of blasting depends on the rock itself, the type of excavator and the production required from that excavator. Many different blast designs are needed even on small sites if the blasting is to be efficient and cost effective.

(d) Draglines require the rock to be broken to a greater degree than either rope or hydraulic shovels. It is necessary to have a dragline sitting as close to the highwall as possible, so that the blast must be designed to avoid disturbing this free face.

(e) Hydraulic shovels have greater breakout forces than rope shovels so can dig harder, or less well fragmented rocks.

(f) The major differences between opencast coal mining in the UK and that in other parts of the world are the scale of most operations and their proximity to centres of population. In the UK a site will often have houses adjacent to its boundary and in some cases live services crossing the site itself.

(1) Energy is released directly into the air by the use of exposed detonating cord. This is minimised by ensuring that the cord line is covered by drilling dust or other final material. (British Coal currently specifies that all detonating cord be covered to a minimum depth of 300mm).

(2) High pressure gases are generated by the confined detonation and these are released into the air. This effect can be minimised by ensuring the blast holes are properly stemmed and the explosive power is confined within the rock.

(3) The blast causes the rock surface to move. Here the nuisance can be minimised if any free faces are directed such that the generated pressure wave will have least effect.

The direction, distance of travel and the intensity of the airborne vibration is dependent on the wind direction and speed, and on the cloud cover. On a cloudless still day a blast may be barely audible a 1/4 of a mile away, but on a day with low continuous cloud cover the same blast may rattle doors and windows up to 3 or 4 miles downwind.

Ground Transmitted Vibration

The ground borne vibrations are due to a combination of different waves travelling at different speeds, with differing frequencies and principle directions of movement. These all decay at varying distances from the blast. Further discussion of these waves is beyond the scope of this paper.

When an explosive charge is detonated in a confined space the energy is released in two forms. Firstly it generates a shock wave which causes cracks in the rock surrounding the hole. Secondly it produces volumes of gas which seek to enter these cracks and other existing planes of weakness, to open them up forcing the rock mass to further break up and move.

Nitroglycerine based explosives such as plaster, tunnel and opencast gelatines produce large shock waves and lesser volumes of gas. Ammonium nitrate based explosives such as ANFO and slurries produce smaller shock waves and greater quantities of gas. Most of the rocks found in coal measure strata are relatively soft in rock mechanics terms, being mainly sandstones, shales and mudstones. Hence generating shock waves is of lesser importance in breaking the rock than producing a larger volume of gas. In the harder rocks found when quarrying or tunnelling the opposite is the case.

The use of ammonium nitrate based explosives is therefore favoured by the opencast industry. This choice is also influenced by economic reasons. The comparative costs are:-

Velocity Monitoring

Following extensive reserach in USA and Canada in the 1960s and the arrival on the market of portable, rugged instruments capable of measuring the velocity of ground borne vibration, opinion changed in favour of using the speed of the vibration induced as a better factor for predicting both nuisance levels and the possibility of damage. Typical of these instruments were the VME model E and F recorders both of which measured the peak particle velocity (PPV) of the vibration in three orthogonal directions. These instruments utilised geophones which directly measured the velocity of the ground vibrations. Another improvement was the use of galvanometer mounted mirrors reflecting ultraviolet light onto a chart of light sensitive paper as the recording mechanism, rather than the pen and ink roll plotters previously used.

The maximum PPV is related to the scaled distance (SD) between the blast hole and the vibration recorder. The SD is a multiple of the distance between recorder and blast hole, and the weight of explosive detonated in the hole. It is most common to use the square root SD ($SD=d/\sqrt{E}$), but some people prefer to use the cube root ($SD=d/\sqrt[3]{E}$).

The SD is related to the PPV using the formula developed by the United States Bureau of Mines (USBM):-

$$PPV = k \times SD^{-b}$$

where 'k' and 'b' are constants dependent on the rock type and location, and the blast confinement.

Values in the region of 500 for 'k' and -1.5 for 'b' have been calculated from blasting carried out in coal measures.

The Development of Modern Instrumentation

The utilization of microprocessors in vibration monitoring equipment coupled with cheap on-site computers in recent years has opened up the way for improvements in the monitoring and analysis of blast vibrations.

The older types of instrument all produced the vibration records directly onto a chart, after producing the chart the information was lost. The maximum values were found by measuring the peaks off the traces produced, though latterly the equipment was capable of sampling the readings to find these maxima.

Modern monitoring equipment measures the electrical signals from the vibration transducers and stores these readings within the instrument until the entire event being recorded is complete. Readings may be taken at up to 1000 Hertz and depending on the instrument type this sampling frequency may be variable. The equipment then produces a chart showing the vibration velocities recorded together with the maximum values detected. As the individual velocity readings are stored, they can be processed to calculate the maximum displacements, accelerations and frequencies of the vibration in each direction. These values are also printed on the chart.

Data Analysis

With the availability of computers on site linked to data recorders, the individual vibration velocities together with all the maxima are collected and recorded automatically. This recorded data can be transferred to a computer for immediate analysis.

This analysis may take several forms:-

(a) The velocities can be displayed on the computer screen at an expanded time scale for examination at a greater detail than is possible on the recorded charts. The exact detonation time of individual detonators can be estimated, together with any interaction between the different delays (see figures 2 and 3).

(b) The velocities can be intergrated or differentiated to find the displacements and accelerations. These are displayed on the screen for examination (see figures 4 and 5).

(c) Energy vs frequency analysis may be carried out to produce a histogram showing the energy of the vibration at each frequency. The relevance of this analysis is explained later.

(d) The peak values recorded can be combined with previously recorded data and the whole re-analysed to produce a new regression line and new set of confidence limit related predictions (see figure 6).

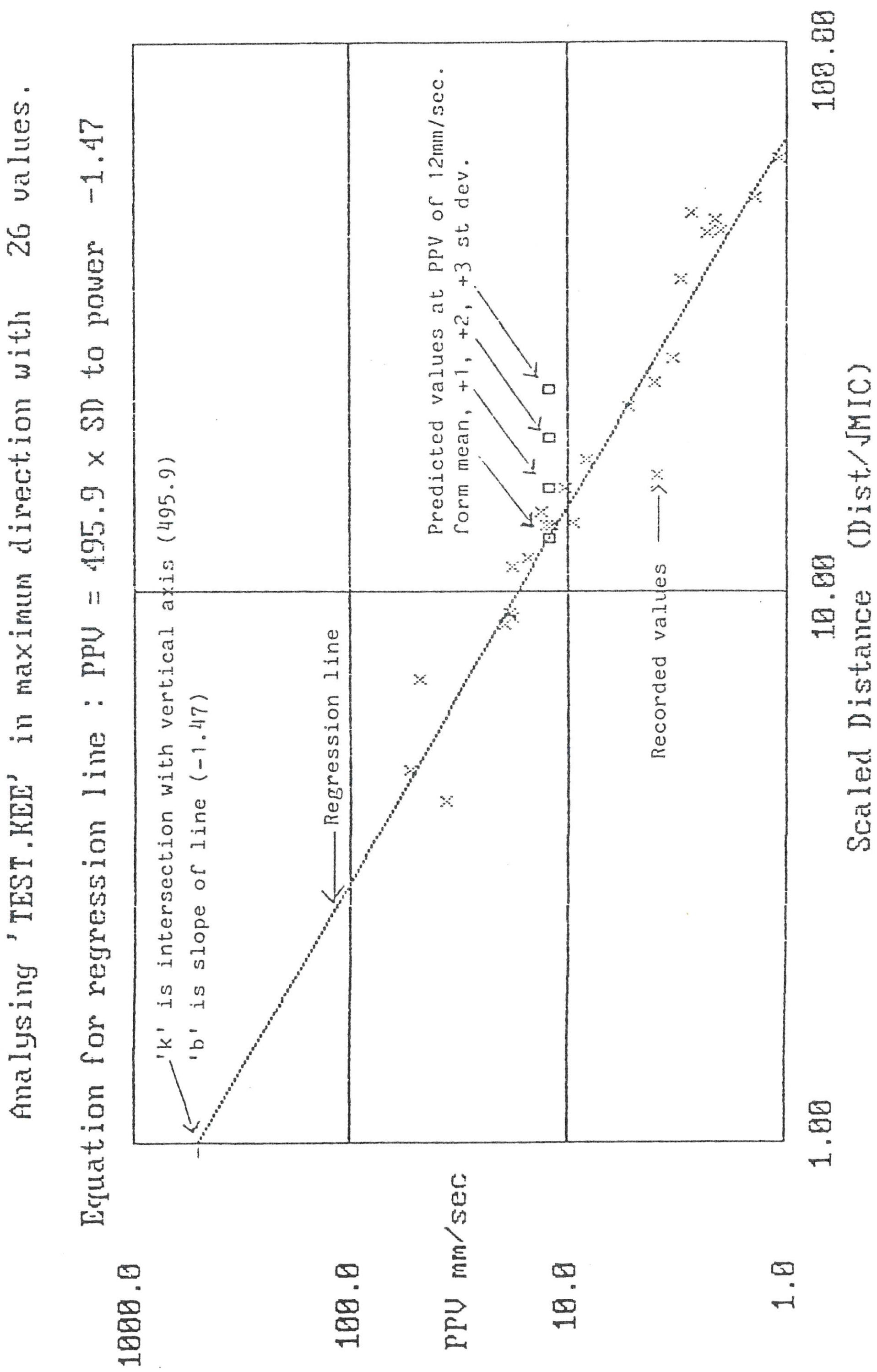
(e) The regression line together with the points used to generate it can be displayed on the computer screen and further readings can be added to the screen display without including these in the analysis. This enables the vertification of particular readings before adding them to the permanent data base of vibration results (see figure 1).

All screen displays can be reproduced on a printer connected to the computer and a permanent copy of any part of the analysis obtained.

Energy Analysis

Velocity as a measure of damage was widely used as it was easy and cheap to record on site. It has long been known that damage to structures is related to a combination of the frequency and energy of the vibrations. Histograms relating the energy released at each frequency can be produced from the individual velocity readings stored in the computer.

These histograms are most useful when measuring vibrations in areas where there are several potential sources. The histogram of blast related vibrations is different from that generated by a vehicle passing close to the transducer or even that from a nearby factory. It has long been felt by those carrying out blasting that they have been held responsible for the nuisance from many sources apart from their blasts. Now by recording and analysing the vibrations it is possible to differentiate between blast related vibrations and those from other sources.



Computer output of a "regression line"

Figure 1

Computer output showing "regression line" constants and change weight predictions for a PPV of 12mm/sec.

Analysis of vibration results

Data is from file 'TEST.KEE'. Date : 12-08-1988

Analysing maximum direction with 26 values.

Equation for regression line : Ln(PPV) = -1.47 * Ln(SD) +6.21

Constants for USBM formula : b = -1.47 : k = +496.0

Standard deviation : 0.32252

Correlation coefficent : -0.96596

Standard error : 0.30987 (Antilog = 1.3632)

Values for plotting regression line.

Peak Particle Velocity :	0.10	1.00	10.00	100.00
Scaled distance :	320.67	67.28	14.12	2.96

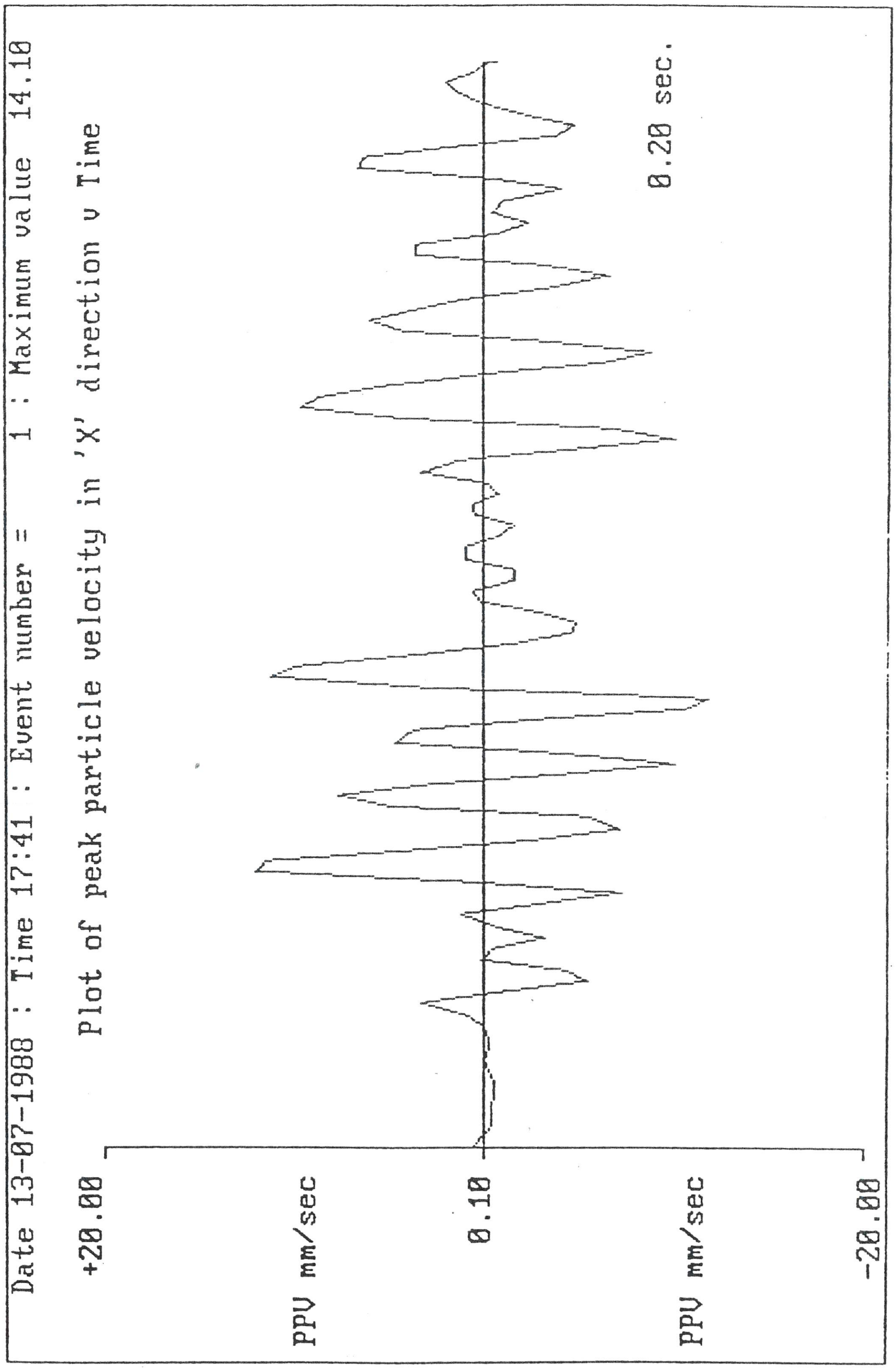
Predicted MIC weights (kg) to give PPVs of 12.00 mm/sec for varying confidence limits (1st method).

Distance in m	40	60	80	100	150	200	[SD	PPV]
Mean value	10.3	23.1	41.1	64.3	144.6	257.0	[12.5	12.0]
1 St dev 84.1%	6.8	15.2	27.0	42.2	95.0	168.8	[15.4	16.4]
2 St dev 97.7%	4.4	10.0	17.7	27.7	62.4	110.9	[19.0	22.3]
3 St dev 99.87%	2.9	6.6	11.7	18.2	41.0	72.8	[23.4	30.4]

Predicted MIC weights (kg) to give PPVs of 12.00 mm/sec for varying confidence limits (2nd method).

Distance in m	40	60	80	100	150	200	[SD]	[t]
Mean value	10.3	23.1	41.1	64.3	144.6	257.0	[12.5	0.0]
Conf Lim 85%	8.1	18.3	32.6	50.9	114.6	203.7	[14.0	0.5]
Conf Lim 97.5%	4.9	10.9	19.5	30.4	68.4	121.6	[15.1	1.7]
Conf Lim 99.97%	2.0	4.5	8.0	12.5	28.1	49.9	[28.3	3.7]

Figure 6



Date 13-07-1988 : Time 17:41 : Event number = 1 : Maximum value 14.10
Plot of peak particle velocity in 'X' direction v Time
0.20 sec.
+20.00
PPV mm/sec
0.10
PPV mm/sec
-20.00

Figure 3

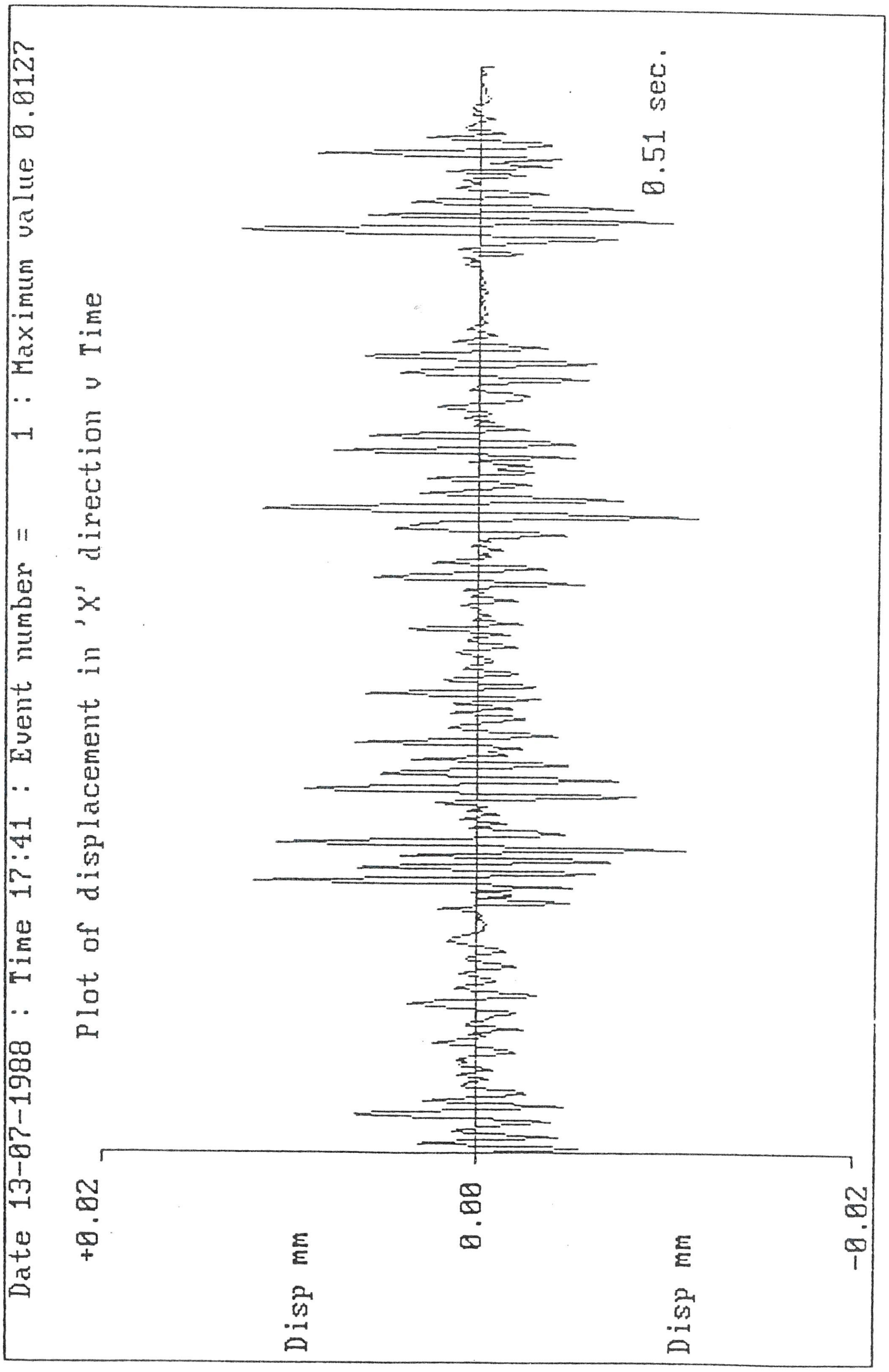

Date 13-07-1988 : Time 17:41 : Event number = 1 : Maximum value 0.0127
Plot of displacement in 'X' direction v Time
+0.02
0.00
-0.02
Disp mm
Disp mm
0.51 sec.

Figure 5