Proceedings of the Institute of Acoustics

THE DEVELOPMENT OF LOW NOISE ON ONSHORE DRILLING RIGS

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INTRODUCTION

In the last ten years, exploratory drilling, to identify potential oil and gas reserves, has taken place at over 50 sites in the south of England. The success rate has been relatively high and the discoveries by both Carless Exploration at Humbly Grove in North Hampshire, and BP at Wytch Farm in Dorset are currently in production. It is understood that other discoveries made to date are expected to be commercially viable.

For an exploration well to yield the quality of information required by the geologists to evaluate a discovery, the initial well should be drilled to a target area which provides entry at the top of the reservoir and in a vertical direction. Thus, there is only a limited area on the surface from which a valid exploration well may be drilled, even if directional drilling methods are employed.

In practice, therefore, it is frequently necessary to locate exploration sites in relatively close proximity to residential properties.

Even though drilling operations are generally completed in 4 to 6 weeks, the local Planning Authorities require noise levels to be minimised, particularly for the sensitive night-time periods. The authorities recognise that it is not possible to achieve inaudibility at nearby housing where, in rural locations, background noise levels may be in the range 20-25 dB(A). It is now typical for maximum allowable noise levels to be limited to 40 dB(A) L_{90} and 45 dB(A) L_{eq} at the nearest housing(figure 1). These levels have been found to be generally acceptable and do not unduly disturb local residents, who are aware of the short term nature of the activities.

GENERAL ARRANGEMENT OF TYPICAL DRILLING RIGS

The rigs currently in general use in the UK are of two basic configurations;

i) Trailer Mounted Derrick

This configuration of rig comprises a trailer mounted derrick and rotary table with separate skid mounted generators, mud pumps and mud treatment packages.

ii) Independent Derrick

This configuration of rig is generally of higher capacity than the trailer mounted type and all items are skid, mounted with the derrick and drill floor mounted on an independent sub-structure.

Some of the rigs used in the UK, when exploration first started were previously used in remote areas of the USA and Middle East, where each major item was driven by large diesel engines which were not enclosed, and the exhausts were only fitted with spark arrectors. Consequently noise levels both around the rig and in the community were very high Gradually, the need to obtain planning permission to drill in sensitive sites has resulted in the major drilling contractors developing new "low noise" rigs or carrying out major noise control on their existing rigs, in order to comply with contractual planning conditions.

NOISE SOURCES

The noise sources on a rig may be divided into two categories; those which operate continuously during the drilling operation and have the major influence on the L_{90} noise level in the community and those which operate intermittently.

The former comprise the main power generators, the mud pumps, the mud treatment package and the rotary table. The latter comprise brake drum squeal, impacts (drill pipe, casing materials handling) and site vehicle movements.

In addition to the sources directly associated with the rig and provided by the drilling contractor, specialist companies' equipment is also required, which could cause potential noise problems. These include, cement pumps, wire line units, logging units, dewatering pumps etc.

NOISE CONTROL MEASURES

Generators

To achieve low overall noise levels the diesel generator sets (usually 2 or 3 are required per rig) have extensive noise control treatment. The engine/generator skid is housed in an acoustic enclosure and is mounted on low frequency vibration isolators with entry via acoustic doors. The cooling air inlet and discharges are via high performance splitter silencers which are 2-3m long. Two engine exhaust silencers are used in series, to provide both reactive and absorptive elements.

The pipework is vibration isolated from the exhaust manifold and acoustic cladding is applied to the body and inlet pipe of the first silencer.

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Mud Pumps
The mud pumps are generally driven by large DC electric motors on low noise rigs (although diesel engines can be used where noise levels are less critical). Again the units are housed in acoustic enclosures with well silenced cooling air ventilation system. The DC motors are supplied with high speed fans for cooling (as the motor speed is not sufficient to drive an integral fan) and the air intake for these fans requires specific attention as they frequently generate high noise levels, which include distinctive tones at blade passing frequency.

Mud Treatment Package
The mud treatment package would comprise hydraulic or electric motor driven shale shakers, electric motor driven charge and circulating pumps and tank agitators, with associated degassers and mud cleaning equipment. Provided this equipment is well maintained, noise levels will be relatively low, however, the shale shakers which typically operate at 15-1800 rpm, radiate low frequency noise (32 Hz octave band) and where, as is typical, two of these units run at the same time, a characteristic "beating" may be evident in the surrounding community. To date, apart from minimising the speed of operation of the shakers, the only form of noise control adopted has been acoustic screens. Total enclosure of these packages has universally been considered as impracticable.

Drill Floor
On the larger rigs, the drawworks and associated drive motor(s) are located on the drill floor. It is essential that there is unrestricted access above the drill floor during drilling activities. Noise control generally takes the form of conventional acoustic panels some 2.5 - 3.5 m high, located around the edge of the drill floor, with access doors for personnel and to allow drill pipe, casing etc. to be transferred to and from the pipe rack. Partial roofing, particularly over the drawworks has also been used on some rigs. The cooling air system for the DC motors are fitted with high performance silencers in a similar manner to those on the mud pumps.

The substructure below the drill floor, while not housing any significant noise sources, is immediately below the drawworks and rotary table and noise levels in this area are relatively high due to both airborne and structureborne noise. The area is subject to frequent drenching in "mud" from the drill floor above, making it unsuitable for sound absorbent materials. The areas is therefore enclosed with steel panels with heavy tarpaulins at one end, to allow easy access in event of an emergency.

The electric motor (or diesel engine) drive and gear train for the trailer mounted rigs are not located on the drill floor and the rotary table is driven via a transmission shaft. Hence, the motor, gearbox and drawworks can be totally enclosed, apart from a relatively small opening required for the drawworks cable. The drill floor is surrounded by acoustic panels, to reduce the radiation of noise from unavoidable impacts and from the rotary table.

The drill floor on this type of rig is only 2-3 m above grade and the congested area below the drill floor is enclosed typically with a combination of heavy tarpaulins and heavy overlapping neoprene or clear pvc strips.

Drawworks Brake
The conventional drawworks drum brake is the major source of intermittent noise and produces a characteristic squeal, with a level of 100-110 dB(A) on the drill floor. Enclosure of the smaller trailer mounted units is effective, although the operation of the brake remains audible. Enclosure of the larger units has, in practice only been of limited benefit. Various alternative brake pad material have been tried but none have achieved lasting reduction in noise levels.

The use of an alternative disc braking system has been very effective and where this modification has been employed, the operation of the brake is barley audible. The system comprises a heavy steel disc with a series of conventional brake calipers. Pressure is applied via a hydraulic activation system.

When originally proposed, there was considerable doubt in the minds of the drilling engineers as to the practicality and suitability of the system, however, it is understood that once the driller has adapted to the different "feel" of the operating lever and the lack of noise, the system has proved to be perfectly acceptable.

Miscellaneous Items
It is inevitable when handling heavy items, particularly the drill pipe and casing, that there will be some impact noise. The use of heavy timber linings on the pipe rack, cat walk, ramp and drill floor, helps to minimise impact noise.

There are occasions when additional plant, not directly associated with the rig is required on site and there may be occasions when such plant has to be used at night. Silenced site generators, 'welding sets', pumps etc are available and those responsible for ordering such equipment must ensure that the sub contractors do provide suitable equipment if the benefits of using a low noise rig are to be fully realised.

Screens
Screens, generally comprising sheets of plywood mounted on a steel framework to an effective height of 5 to 8m have been used on a number of sites, where a small reduction is required in specific directions. However, it is not practicable or visually acceptable to construct the size of screen necessary to achieve a substantial reduction in noise levels.

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THE FUTURE

The development of drilling rigs, which has taken place in the last 10 years has reduced community noise levels by 10 to 15 dB(A) and exploratory wells may be drilled within 200 to 300 m of private housing without causing undue disturbance

It will be difficult to achieve further significant reduction in noise levels associated with the operation of the current type of rig and if exploratory wells are required in more densely populated areas the development of compact "mini" rigs may be the way forward. These rigs drill small diameter holes using short (2-3m) lengths of drill pipe, and require only a small site area. In addition to conventional noise control, their low elevation and compact size mean that acoustic screens could be used effectively in specific directions and it may be practicable to enclose the complete rig.

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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.

(g) The proximity of properties to sites can mean severe restrictions are placed on the Contractor by the Client as to the weight of explosive that can be initiated at any one delay interval. This precludes the use of exotic techniques, such as overburden casting by blasting, carried out successfully in other areas of the world.

(h) The size of the plant used is greater than that found in other extraction industries in this country, so larger rocks can be tolerated, and explosive yields are higher than in quarrying or tunnelling.

(i) Blasting is more frequent than in most quarries and on a larger scale than most tunnels, so the public awareness of the effects is often greater, and the amount of nuisance that is tolerated much less.

(j) The depth of the drill holes varies from 4 to 20m deep, the hole size from 75 and 150mm, the burden and spacing from 2.5 to 6.5m, and the explosive yield from 2.5 to 6 cu.m. per kg. Both 'drifter', 'rotary' and 'down the hole' type of pneumatic and hydraulic drill rigs are used.

The Effects of Blasting

When blasting takes places, two forms of vibration can be produced, airborne and ground borne. The greatest problem encountered by anybody involved in the environmental impact drives from the fact that the human body is very sensitive to vibrations particularly those produced when blasting. Vibrations far below a level which could cause structural damage or even minor cracking are easily discernable.

A seated person will feel a vibration with a peak particle velocity of only 1/2 or even 1/4 mm/sec, if it has a frequency in the range 5 to 20 cycles per second (Hertz). It has been shown that structural damage is unlikely to occur at levels below 100 mm/sec, and cracking of plaster below 25 mm/sec. The natural frequency of the human body is between 7 and 15 Hertz, depending on the build of the person. Vibrations as small as 5 to 10 mm/sec at a persons natural frequency will feel very uncomfortable, especially if they occur regularly and have durations of several seconds.

Close to a blast a large range of frequencies is present, but the low frequencies travel furthest, and these are the frequencies that annoy people rather than cause damage. The problem facing those responsible for blasting is how to convince the average 'man in the street' that despite the apparent strength of the vibrations they are still at levels too small to cause damage.

Unfortunately the result for the Contractor is that restrictions on blasting vibrations are determined by what people will feel and be aware of, not on what will cause damage.

Air Transmitted Vibration

The main effect of the airborne pressure wave is to rattle loose doors or windows, rather than cause structural damage, but this in itself can be alarming to the unsuspecting public. The three causes cited for the initiation of this vibration are:-

(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:-

Explosive	Cost per kilogramme
Site mixed ANFO	25p
Factory mixed ANFO	55p
Ammonium nitrate based slurries	90p to 170p
Nitroglycerine based explosives (and Emulsion explosives being introduced to replace NG)	168p to 270p

The best way to reduce the ground borne vibrations is to ensure the rocks being blasted are properly fractured with the maximum energy used in breaking the rock not producing vibrations. This is done by ensuring the explosive charge within a hole is sufficient to break the rock through to the adjacent holes. Whilst the size of vibration generated is proportional to the weight of explosive in overall terms, a hole that is undercharged and does not break the rock through to the surrounding holes will produce greater ground vibrations than an identical hole with a larger charge that gives proper breakage.

Monitoring Ground Vibrations

Up to 3 years ago it was the instrumentation available that influenced how the vibrations were measured and how the results were interpreted. The use of microprocessors within the instrumentation itself combined with the existence of personal computers on most sites has brought about a revolution in the recording and analysis of ground borne vibration.

Displacement Monitoring

Until the late 1960s only single channel instruments of the 'miniwriter' type were portable enough to use on site for short term monitoring. These recorded the displacement of the ground, due to the vibration, in a single plane. The displacement recorded was related to the explosive charge initiated using the Morris formula:-

$$A = \frac{k \times \sqrt{E}}{d}$$

where A = Maximum displacement of the ground (mm)
E = Explosive charge weight (Maximum Instantaneous Charge) (kg)
d = Distance from the blast hole to the vibration monitor (m)
k = A constant that is dependent on the site.

Using metric units the maximum value obtainable for 'k' on a coal site is about 2.4, but values as low as 1.0 are often found.

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.

Some modern vibration monitors contain an integral disk drive on which all the individual velocity readings can be stored. Others allow the connection of a portable data storage unit which can store all the recorded information so that it may be transferred to the office for further analysis.

The instrumentation is self triggering and the user sets the level at which the recording of vibration is to start. Recording continues for either a predetermined time, or until the vibration fades. Both the monitors and data collectors are battery powered, so can be left to operate in remote parts of a site or in buildings having no electricity supply for periods of up to two weeks.

Present limitations in the technology required to store the data mean that only 50 blasts can be stored before the data storage unit needs emptying. As these units cost between £4,500 and £8,000 it is unlikely they would be left unattended for many days at a time.

Regression Analysis

The use of the USBM formula to predict vibration levels, requires the PPV to be plotted against the SD on log log scaled graph paper. The best straight line through these points is the 'regression line'. The slope of the line and its intersection with the vertical axis give the values for 'k' and 'b' in the USBM formula (see figure 1). This line is used to predict the PPV at any given location due to a particular blast. The values recorded for PPV vary considerably from the regression line even in homogeneous rocks, so the presence of faults and discontinuities often found on coal sites make the accurate prediction of vibrations even more difficult.

To allow for the variations encumbent in predicting PPV, the standard deviation of the regression line is calculated. When predicting the SD used to calculate the weight of explosive that can be detonated without exceeding a given PPV, it is necessary to know the confidence with which the predictions are to be made. This involves applying a 'confidence limit'. The relation between confidence limits and standard deviation (St dev) are as follows:-

Confidence Limit	Design Limit	Usage
84.1%	Mean + 1 St dev	Normal
97.7%	Mean + 2 St dev	Normal
99.87%	Mean + 3 St dev	Cases of extreme sensitivity

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.

Conclusion

Good blasting practice is a combination of the following:-

(a) Good blast design, taking full account of the face profile.

(b) Holes accurately set out, aligned and drilled to the right depth.

(c) Holes correctly charged and stemmed with proper material.

(d) Care taken to ensure the best detonating sequence.

Following this practice is the best way to ensure that the maximum amount of energy is utilized in breaking the rock and that as little as possible is converted into nuisance. The rock must be properly broken. If the blast design is such that this is not achieved then it is likely to produce higher levels of vibration. It has been demonstrated that reducing the weight of explosive in a hole does not necessarily result in a lower level of vibration.

The best estimate of nuisance and probable damage from blasting is not one single factor but rather a combination of the vibration displacement, its velocity, its frequency, the energy released, blast duration, the number of times a day and total duration of the blasting process. It is a complex area in which to try and predict both damage and general nuisance. Now it is possible to analysis all this data both easily and cheaply, we will be able to predict more accurately the total effect of blasting on the local environment.

Acknowledgements

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(3) New, B.M. (1986), Ground Vibration caused by civil engineering works. TRRL Research Report 53.

(4) Evaluation of human response to vibration in buildings (1Hz to 80 Hz). BS 6472: 1984.

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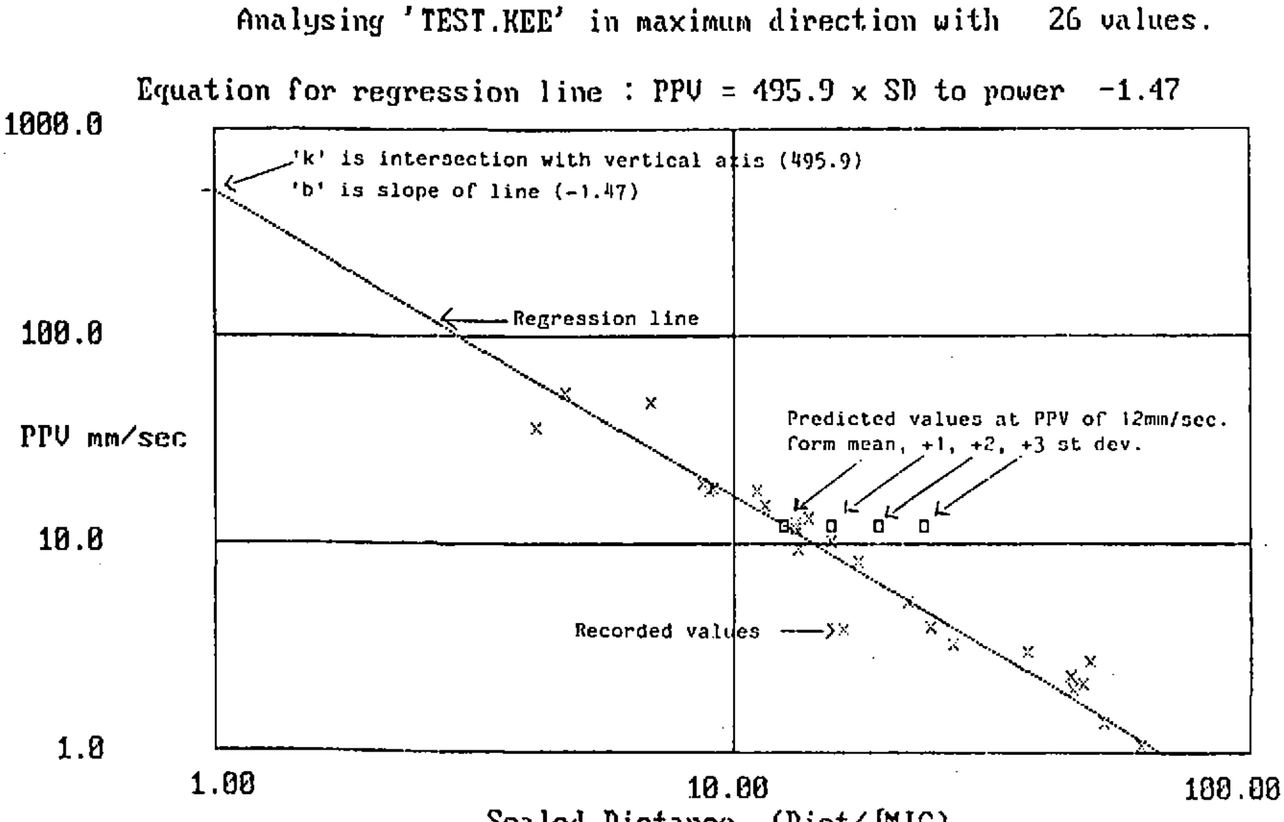

Computer output of a "regression line"

Figure 1

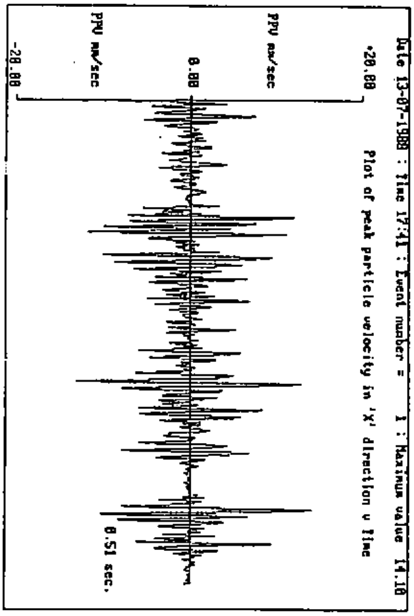

Figure 2

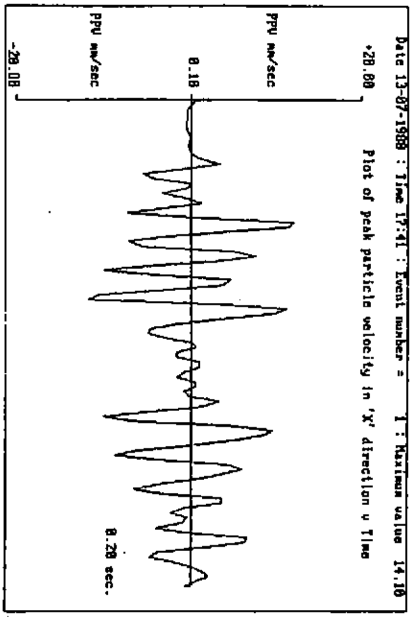

Figure 3

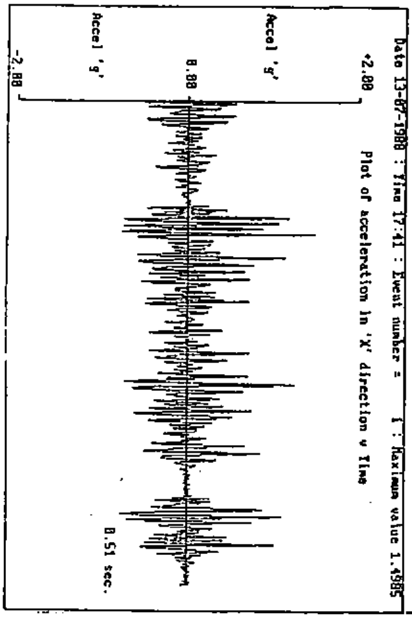

Figure 4

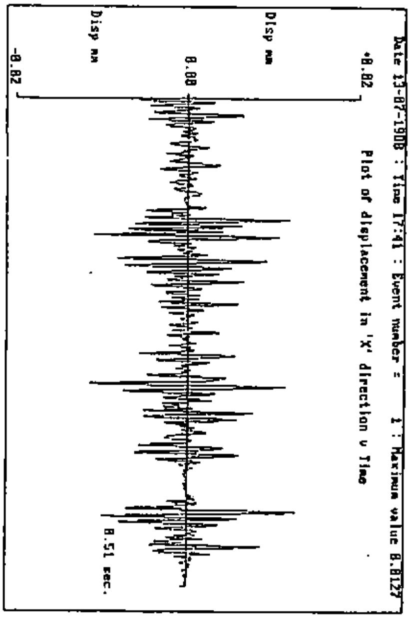

Figure 5

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

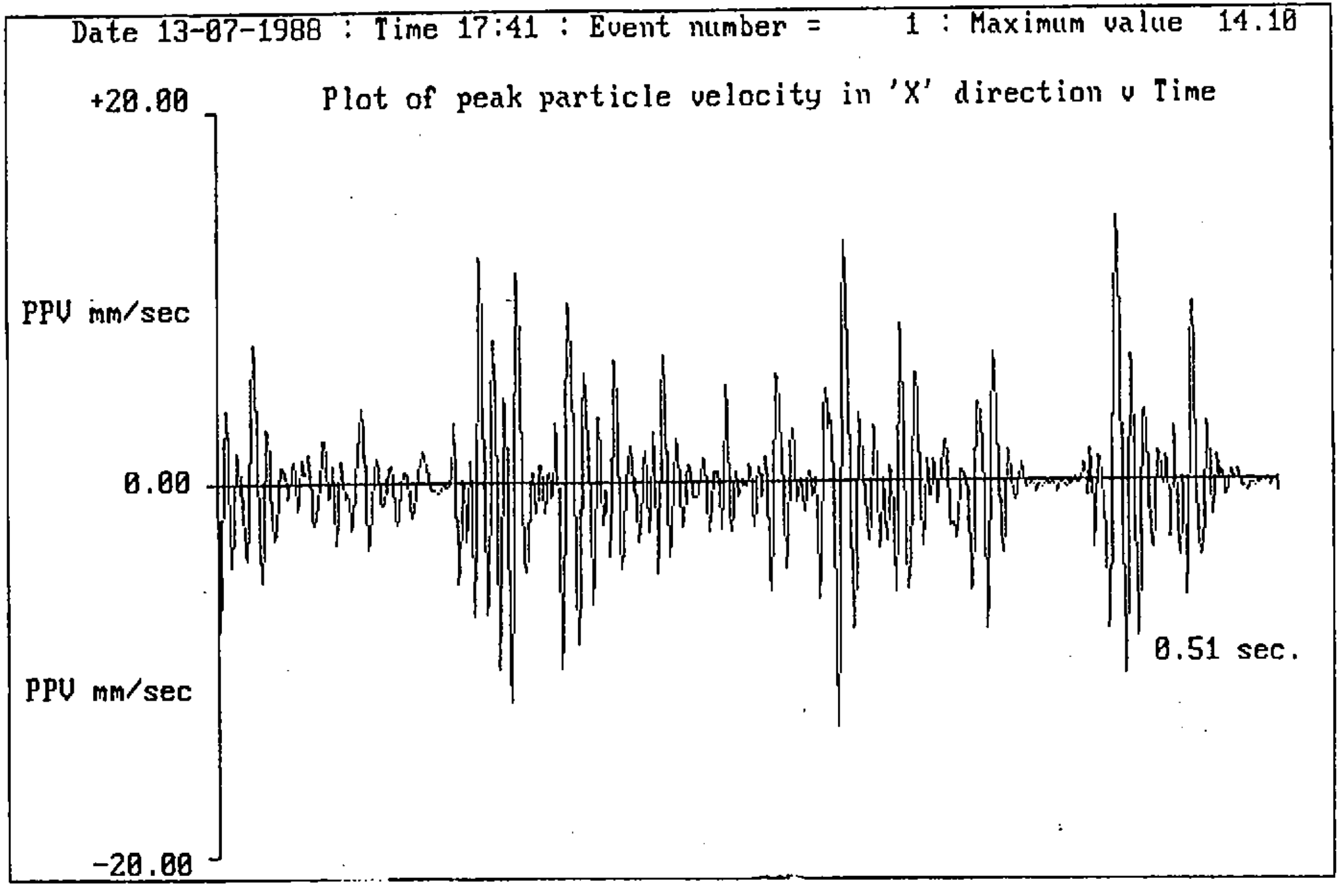
Date 13-07-1988 : Time 17:41 : Event number = 1 : Maximum value 14.10
Plot of peak particle velocity in 'X' direction v Time
+20.00
PPV mm/sec
0.00
PPV mm/sec
-20.00
0.51 sec.

Figure 2

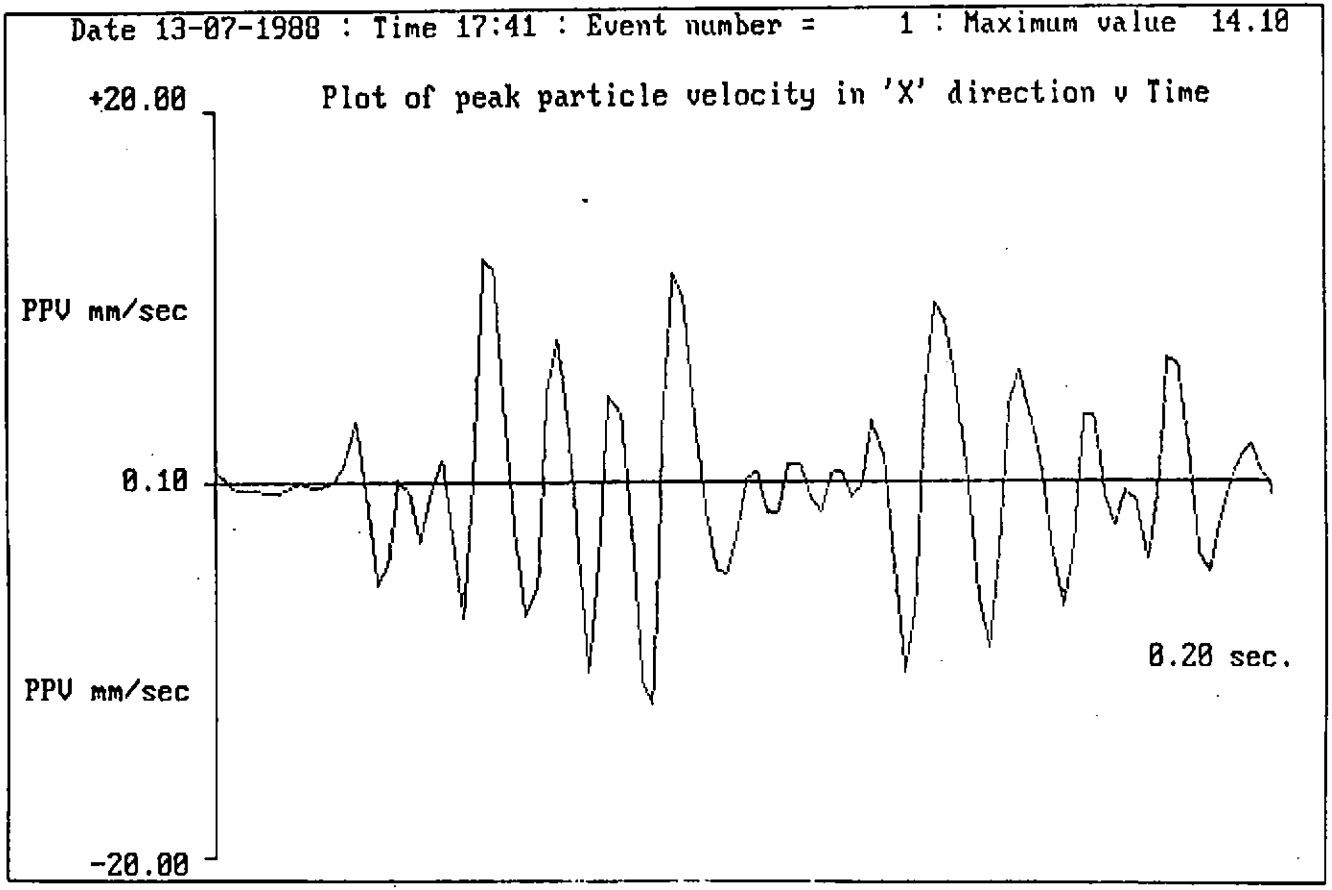
Date 13-07-1988 : Time 17:41 : Event number = 1 : Maximum value 14.10
Plot of peak particle velocity in 'X' direction v Time
+20.00
PPV mm/sec
0.10
PPV mm/sec
-20.00
0.20 sec.

Figure 3

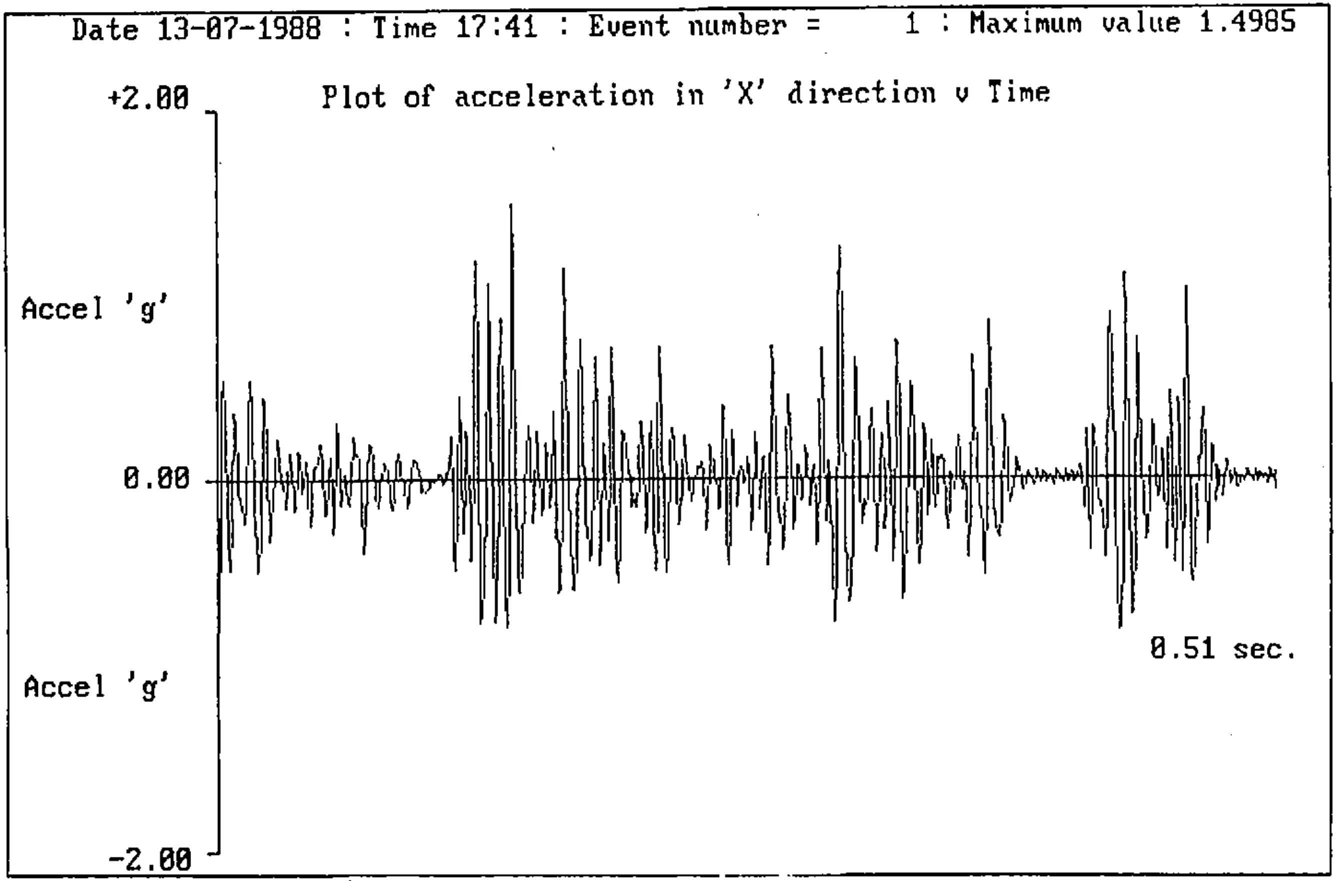
Date 13-07-1988 : Time 17:41 : Event number = 1 : Maximum value 1.4985
Plot of acceleration in 'X' direction v Time
+2.00
Accel 'g'
0.00
Accel 'g'
-2.00
0.51 sec.

Figure 4

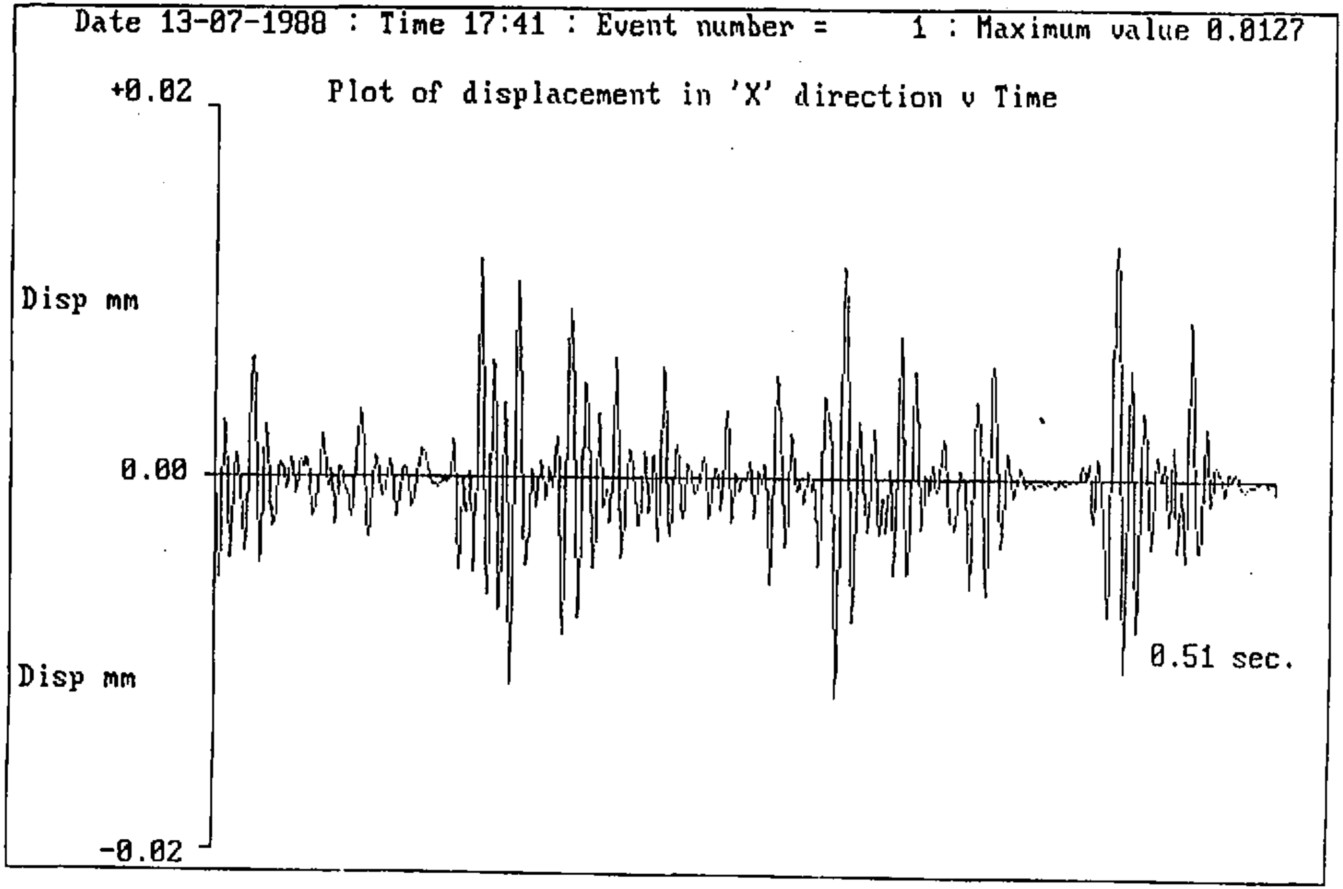
Date 13-07-1988 : Time 17:41 : Event number = 1 : Maximum value 0.0127
Plot of displacement in 'X' direction v Time
+0.02
Disp mm
0.00
Disp mm
-0.02
0.51 sec.

Figure 5

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

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