The database management of piling induced ground vibrations

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The Database Management of Piling Induced Ground Vibrations

by

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Abstract

The storing of ground vibration signals produced by pile driving have been stored in a database on a Nimbus personnel computer. The signals were recorded on a purpose built data logger in the form of time history traces, analysed to calculate the maximum values and then these values transferred. This report covers the design of the transfer systems and the database itself, the manner in which the transfers were effected and a description of the support software produced. Data acquisition is also covered to provide an insight into why certain database design features were included. An expert shell system has also been designed, allowing predictive estimations of ground vibration levels to be achieved. Comparisons between the two systems suggest a good level of compatibility.

Declaration

All of the work contained in this thesis does not appear in any other thesis and is all the work of the writer.

Acknowledgements

The writer would like to thank the members and staff of the Applied Mechanics Group at Durham University for their support and assistance throughout the term of this project. In particular I would like to thank Prof P.B. Attewell, Dr A.R. Selby and Ali Uromeihy for their continual help and advice. Also I would like to thank Trevor Nancarrow and Ian Wallis for their computing advice, support and inspiration. The support of British Steel has been greatly appreciated.

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1. Introduction

The driving of steel piles in construction projects is an increasingly common occurrence. The piles are driven by either impact or vibratory hammer through weak soils into strata of greater bearing capacity. The high levels of energy used in the driving of such piles causes vibration waves to emanate radially from the source of piling. These waves are discernible to humans and in severe cases may be damaging to structures. Much work has been carried out in this area, namely by Attewell and Farmer (1973), Walton (1990) and Steffens (1985). A ground vibration database has been developed to provide reference information on measured ground vibrations. Building upon this database, an expert system has been constructed to provide guided estimation of levels of vibration on future ground vibration projects.

1.1 Piling

In this country the driving of piles has one of two main functions :

1) To transfer loads from a structure to ground strata of adequate strength and stiffness to support them without intolerable displacement, or

2) To construct a continuous wall capable of carrying transverse loads from retained earth and possibly

water, again without intolerable displacement.
In the former case the piles may be of steel H section; however precast concrete piles can also be employed. In addition, a wide range of piling methods is available (see Tomlinson, 1977; Whittaker, 1976; and BS8004 Foundations, 1986). In the latter case, interlocking sheet piles are used (see figure 1.1., and the British Steel Piling Manual, 1988).

As inner city construction and major civil engineering projects increase, the use of piling becomes more prevalent. It may offer economic benefits over deep raft foundations and is widely used in the construction of buildings, bridges, sea defences and temporary works.

1.2 Installation of Steel Piles

There are two main methods of driving steel piles into the ground - impact or vibration. There are other methods such as jacking/vibration or jacking, but these processes are not common in site practice.

An impact hammer operates by striking the top of the pile and thereby imparting energy to that pile. By the conservation of momentum this blow will drive the pile downwards into the soil. The amount that the pile is driven per blow depends upon the efficiency of the blow, the condition of the soil and the precise nature of the pile being driven (see figure 1.2). The mechanism for producing the impact required to drive the pile is described in Figure 1.3.

A vibratory hammer uses the weight of the pile and hammer to provide the driving force. The hammer is clamped to the top of the pile and vibration is set up by contra-rotating eccentric masses, at a frequency of around 25 Hz. This vibration reduces the friction at the soil/pile interface and at the toe, partially liquefying the soil particles present. The combined weight of hammer and pile then cause the pile to be driven into the ground. This hammer is only suitable for granular soils because cohesive soils are not prone to liquefaction. Some modern vibrodrivers operate at much higher frequencies, circa 40 Hz, in an attempt to decrease the level of the transmitted ground vibrations, and in particular to cause more rapid attenuation.

Both processes involve the input of high levels of energy into the pile. This energy passes through the length of the pile as a stress/strain wave and some enters the soil at the toe. This transfer of energy causes the vibration waves to expand radially outwards around a quasi-spherical wave front. Other sources of energy have been discussed, eg Selby (1989).

1.3 Ground borne vibrations - their effects on humans and structures

The human frame is extremely sensitive to vibration, being able to discern particle velocity levels as low as 0.3 mm/sec. This sensitivity increases with the frequency of the transient wave and relatively low levels of vibration can become annoying at higher frequencies (Steffens 1985). This is of particular importance to the high frequency vibrodrivers and their effect on the human frame. Not only are humans good at detecting vibrations but they also tend to exaggerate the level of perceived vibration. This compounds the problems of piling within an inner city area.

The environmental aspect of vibrations affecting humans must be placed alongside the effect on the direct locality. Man made and naturally occurring structures are susceptible to damage caused by pile driving. This damage may take the form of subsidence, ground instability, cracking of building elements and, in exceptional cases, collapse. Care should be taken in the design stage of a construction project to limit piling vibrations in the close proximity of sensitive structures.

There are several codes of practice giving guidance on levels of vibration for the construction industry, these being notable for their differing interpretations. At the time of writing there is a draft British Standard Code of Practice (BS 5228) in circulation. This recommends tolerable levels of vibration for both humans and structures and represents a standard for quantifying and regulating pile driving operations.

Structures can withstand reasonable levels of vibration, and a velocity of 10 mm/sec for transient vibrations is often quoted as being a limit for domestic buildings. This is regarded as the level at which plaster may crack and inconvenience may be caused to the occupants of the structure. The natural frequency of the composite structure is very important as continuous vibrations close to this frequency may result in severe damage. In general a building will have a lower natural frequency than that of its component parts.

1.4 Objectives of thesis

In order to advance the understanding of ground borne vibrations produced by pile driving a database have been set up to store collected data. The data has been collected from some 130 visits to sites throughout the United Kingdom. This data can then be analysed to perceive the effect of individual independent variables on the level of ground vibrations. The database may also be used as an aid to subjective prediction of the level of probable vibrations at a new site. This is achieved by examining records at visited sites which closely resemble the proposed site. To this end the database was constructed in a manner which facilitated structured query routines.

The database is capable of producing reports of recorded velocity, acceleration and displacement in radial, transverse, vertical and resultant components.

The expert system utilizes sub-groups from within the database (together with databases on hammer energies and other aspects) and applies the logarithmic approach used by Attewell and Farmer (1973).

This thesis represents a contribution to the ongoing research effort at Durham University into the subject of ground vibrations.

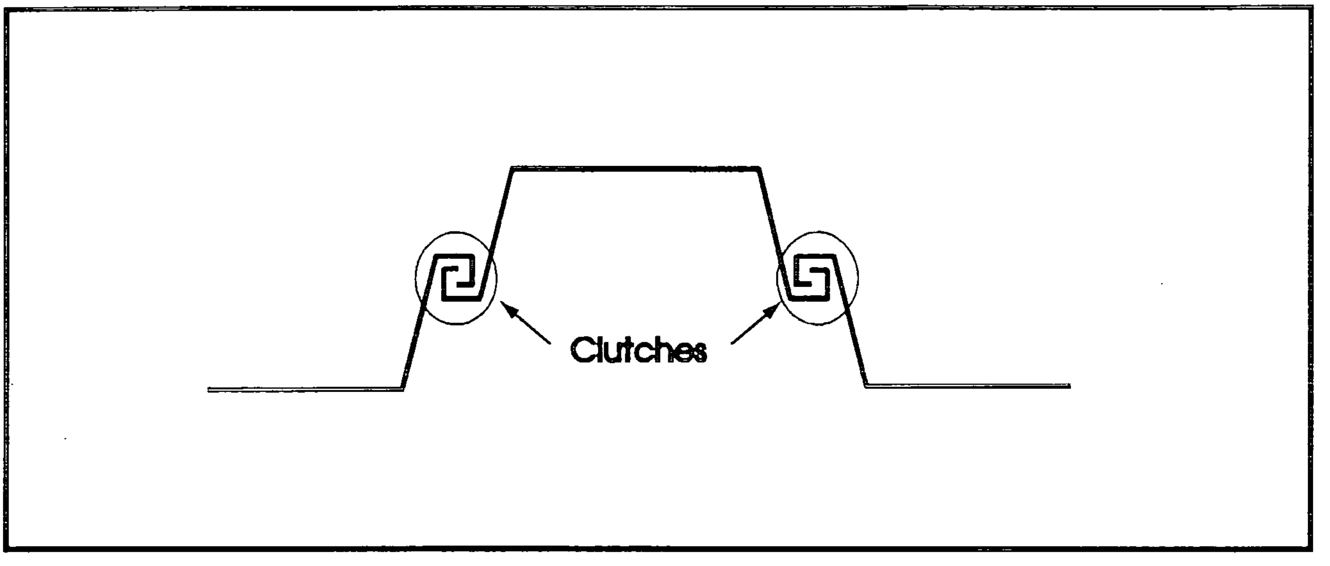


Figure 1.1

Schematic diagram showing the joining of sheet piles.

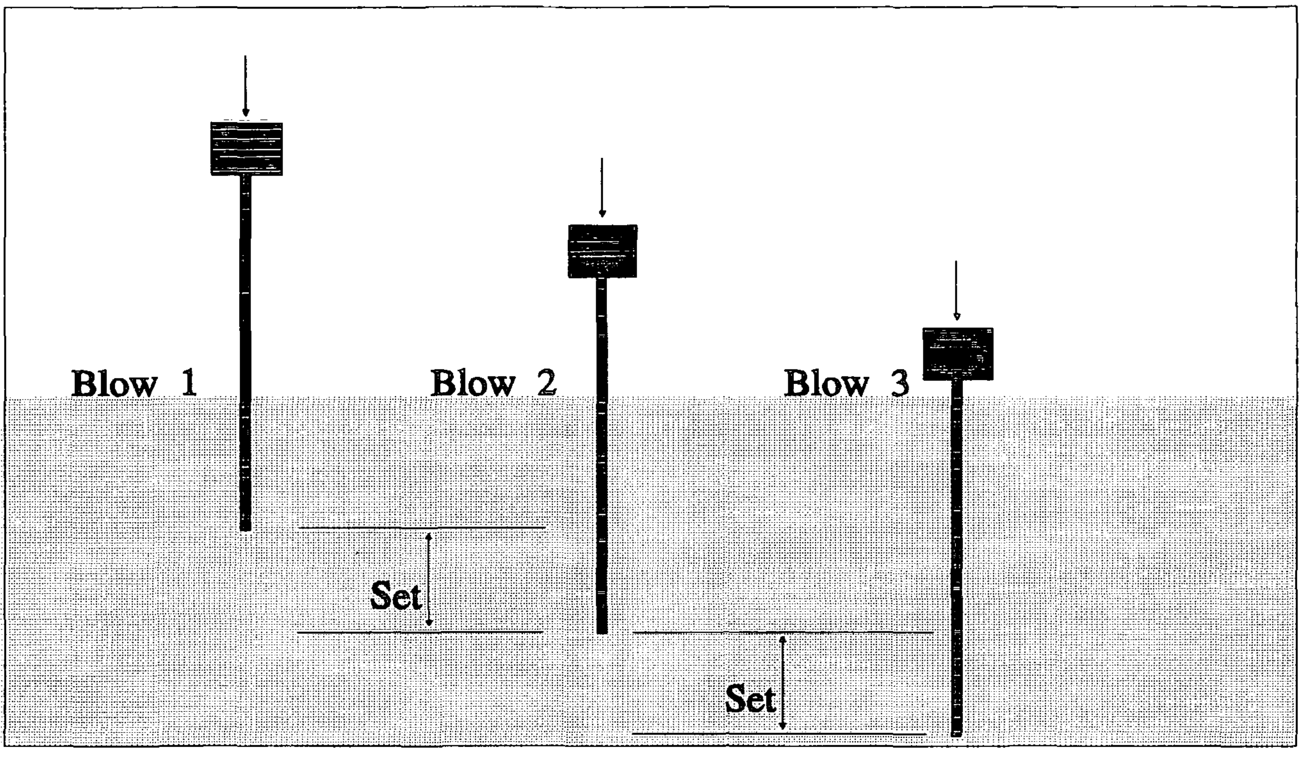


Figure 1.2a - Driving in loose granular soils

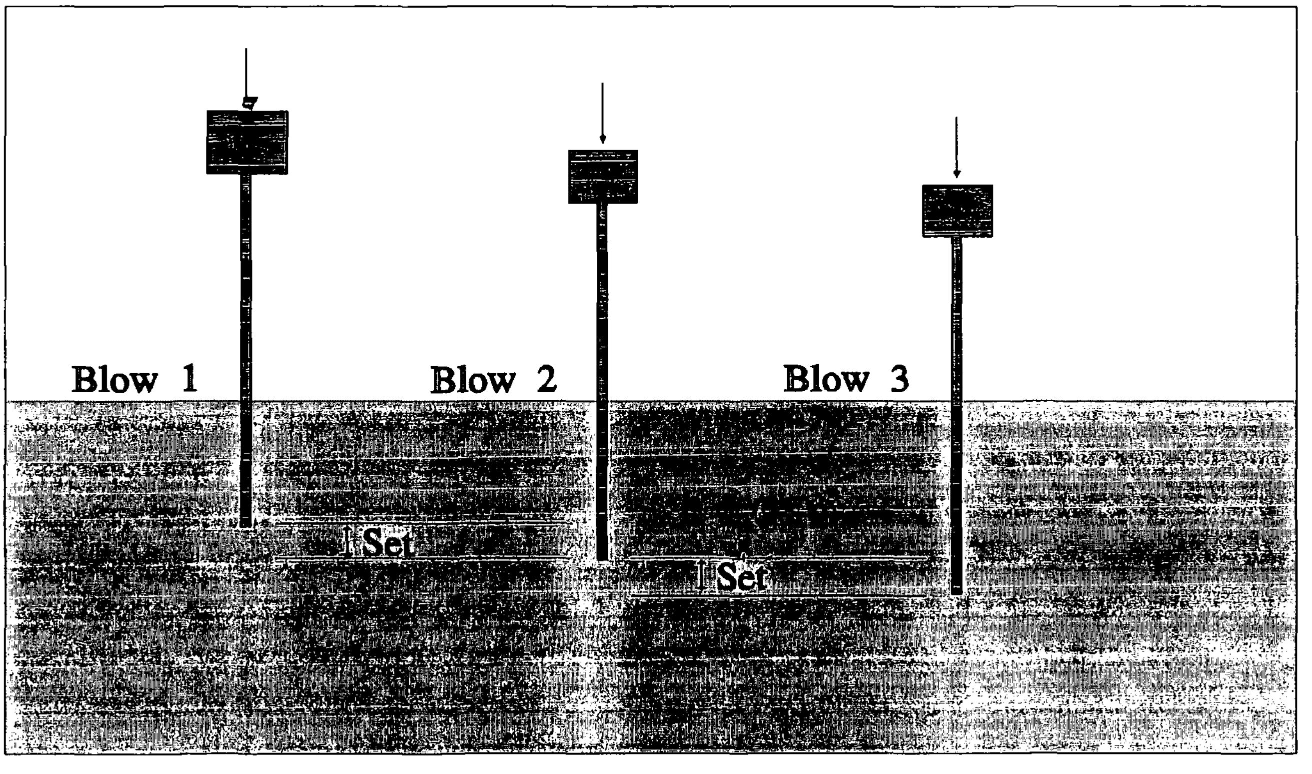


Figure 1.2b - Driving in stiff cohesive soils

Figure 1.2 - Effects on Drivability

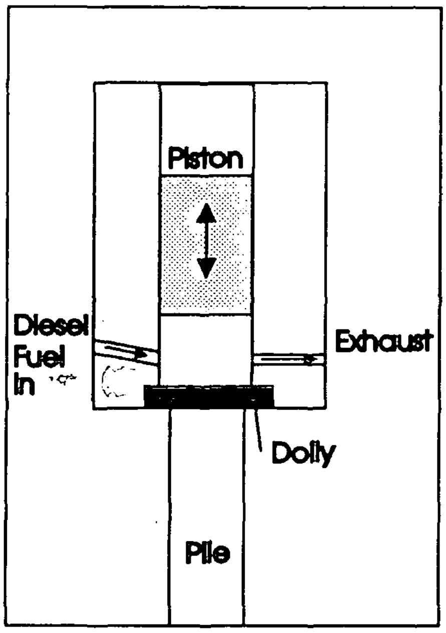


Fig 1.3a

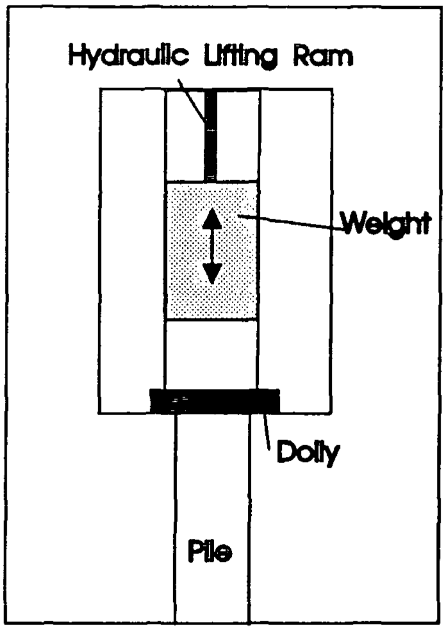


Fig 1.3b

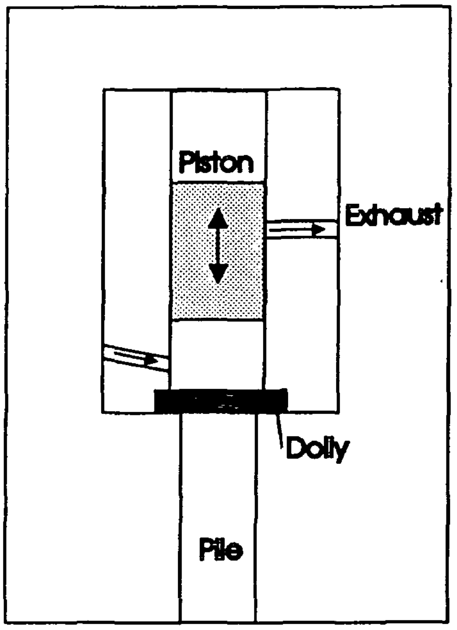


Fig 1.3c

1.3a) Diesel Hammer - Piston raised by repeated explosion of diesel fuel

1.3b) Drop Hammer - Weight dropped repeatedly either by winch or hydraulic pressure

1.3c) Air Hammer - Piston raised by repeated use of compressed air

Figure 1.3 - Different operation of impact hammers

2. Site Measurement

The recording equipment used to capture ground vibration site data was designed and manufactured by the Microprocessor Centre of Durham University. Sites throughout the United Kingdom were visited, always with prior permission from the site agents concerned. Whilst data could be stored on disk and analysed at the University, the equipment was capable of producing immediate results and graphical output. The equipment was also capable of measuring vibration levels from sources as varied as church bells to a drop forging process.

2.1 Equipment

A system to measure and record ground surface vibrations requires transducers to convert mechanical vibrations into electrical signals, and a measurement/storage system for the voltage signals. The data acquisition unit (PDR2) used to collect the ground vibration signals is based on a Motorola 86020 32 bit microprocessor. This provides the powerful computational capability required to monitor all the data channels and control the analogue to digital convertors (ADC's). The four ADC's are each capable of sampling 8 channels, and the order and frequency at which they sample may be manually adjusted. One megabyte of Random Access

Memory (RAM) is used as a temporary store for the digital data output from the ADC's. When manually set vibration triggers levels are exceeded, the relevant section of data can be stored and then permanently saved onto one of the two floppy 5.25" disks. A graphical description of the flow of data through the data logger is shown in Figure 2.1. Two disk units are included so that if one disk drive fails due to adverse conditions, data may still be saved. The back of the unit contains ports for the connection of up to thirty two transducers.

The ground vibrations were converted into electrical signals using velocity measuring geophones. Each geophone consists of a damped spring mass and a permanent magnet which can move relative to a coil. If the geophone is sturdily attached to the medium transferring the vibrations the coil will move with the medium while the magnet will stay relatively at rest. These movements produce a small voltage proportional to velocity (Faradays Law) and this voltage is fed into the data logger. The geophones are laid out in groups of three to measure the radial, transverse and vertical components of the waveform at each of five stations (see Figure 2.2). When the signals arrive at the data logger they are passed to the ADC's where the analogue signal is digitised. These digitised signals are fed into the memory of the data logger whilst the configuration software scans the signal magnitude to see if the trigger levels have been exceeded. The memory buffer of the logger is constantly being refilled with data, and the oldest data is continuously replaced. Once the trigger level is reached the relevant sector of memory is "halted", that is the filling process stops and the data can be saved to disk. This process allows per-trigger data to be stored. The raw data is thus stored as a series as numbers proportional to the voltages output from the geophones. Software facilities on PDR2 allow calibration factors to be applied to this data to convert them into particle velocities at discrete time intervals of around 0.5 ms. The software is also capable of scanning individual channel data for peak particle velocities, including time based vector resultants. A more comprehensive description of the equipment is contained in Selby and Swift (1989) and Uromeihy (1990).

2.2 Site Procedure

Prior agreement with the site agents concerned was always a pre-requisite for each site visit. On several occasions the investigators were actually requested to visit a particular site as specific problems had arisen. The main objectives at a site were to collect as much valid data as possible, to cause the least amount of interference with site operations and to complete the task as quickly as possible.

Typically 5 groups of three geophones would be laid out in a straight line away from the piling. This was not always possible due to the nature of the site, an often occurring difficulty being keeping the geophones at the same level. Before data were actually recorded, the system would have to be set up and configured for a particular site. Variables including the type of hammer, the pile section and length, the condition of the ground and the positioning of the geophones would noted for record. Once the software was configured a trial run would ensure that all the systems were in working order.

As the piling progressed, the ground vibrations produced were recorded along with data relating to the depth of the toe of the pile, a guide to the penetration per blow (set) and the operation of the hammer. All the site constants were also noted for future use. An example site data sheet is shown in Figure 2.3. If required, the data could be analysed on site to give an immediate result to the site representatives. However, the data would normally be analysed in the laboratory.

In total some 140 individual site visits were made; a full site diary is attached in the Appendices.

2.3 Typical Records and Tables

The equipment used to record the data was capable of recording simultaneously all three orthogonal components of velocity (see Figure 2.4). This data could be analysed later to produce the appropriate displacements and accelerations (see Figure 2.5). The three components could also be mathematically resolved into a representative vector resultant (see Figure 2.6). Fast Fourier Transforms could be carried out to identify the dominant frequencies of the waveform. These graphical outputs provide valuable understanding of the nature of the waveform and the characteristics of attenuation. If the parallel signals (eg radial) from several stations are plotted on the same graph, the progress of the waveform can be clearly appreciated (see Figure 2.7).

The results of early site visits were all tabulated for easy reference, (see Table 2.1). However, once the database was operational this process was not carried out because the reference was now the database. Reports from the database are shown in the Appendicies.

2.4 Difficulties and Scope of Work

Due to the nature of the construction industry, where normally the scale of the work is large, collecting accurate and precise data is difficult. Construction sites are open-air busy places, very different to laboratory conditions.

One problem during measurement is vibration caused by other sources - construction traffic, generators, compaction and the like. To minimize the effect of this background vibration care was taken to place the geophones and the logger unit itself in an area as far removed as possible from these sources. The portable generator used to power the data logger is also a vibration source and was not be placed near any of the geophone sets. The logger's software, as previously mentioned, has a very flexible configuration routine which allows software triggers to be set. These triggers allow non-piling specific vibrations to be disregarded, data only being captured data when the geophone set nearest to the piling indicates that piling has commenced. Even if the background levels of vibration are quite large they can be analysed separately due to their individual and easily identifiable frequencies.

Due to the nature of the proposed database, it was important that each recording was consistent with any other. This entailed always trying to place the geophone sets in the same logical order, keeping the geophones level and ensuring that they were orientated correctly. This orientation, radial positive pointing towards the source of the piling, ensured that the data always keeps the same directional sense. This orientation is demonstrated by the right hand rule in Figure 2.8. Ensuring that the geophones were at the same level and on the same line was not always possible and if any deviations were necessary these were carefully noted. Fixing the geophones to the ground was difficult when recording on a coarse grain soil such as dolomite, or on concrete. Normally the geophones were spiked into the ground using three 2.5" locators. In adverse situations these locators could be removed and the unit was solidly positioned with sandbags or a cairn of bricks. This is very important because the operation of the geophone relies on the unit being solidly fixed to the ground surface and responding conformly with it.

Hardware failure was rare, but frequent enough for precautions to be taken. The soldered connections on the geophones themselves occasionally failed. This led to fluctuating and non-sensical results from that particular geophone. A soldering iron was always carried so that on site repairs could be carried out. The risk of total disk failure, mainly due to the ingress of soil particles, was reduced by the presence of the second disk drive. Complete failure of the unit itself only happened on one occasion and on subsequent repair was found to be a result of general wear and tear.

Considering the adverse conditions in which the unit was required to operate it performed excellently throughout.

The equipment was designed specifically to monitor the ground vibrations caused by pile driving. However it was used also in a variety of different applications. Several quarry blasts were monitored, data being recorded as far as 500m from the source of the blast. In cases such as these, extension cables were fitted to the geophones allowing a large distance to be covered with instantaneous signal capture. Tests were carried out to ensure that no noticeable voltage drop occurred when these 200m extensions were fitted, confirming the validity of the results.

If construction was taking place in the locality of a vibration-sensitive structure, requests to visit the site in order to monitor the vibration levels were often made by the owners of the structure or the plant operators. This work was normally unsuitable for use in the database as the geophone layout was irregular. However valuable subject knowledge was gained.

The vibrations caused by the ringing of church bells has been investigated on several occasions, see Attewell, Selby and Wilson (1988). The frequency of oscillation of the bell tower was very low, circa 4Hz, and yet the equipment was still capable of providing useful results. Traffic vibration, both rail and road, has also been measured, some results of which are shown in Table 2.2.

2.4.1 Dornock Firth Road Bridge

One of the most difficult tests for the equipment was undertaken in February 1990. The incremental-launch bridge being constructed on the A9 at Dornock relied upon the piling and concrete casting operations being carried out at the same time (see Figure 2.9). There was a request to monitor vibration levels at different piers whilst the piles were being driven. These piers were 46m apart and some doubts had been raised regarding possible reduction in bonding strength of the reinforced concrete due to the vibrations emanating from piling activities. Whilst little or no vibration would normally be expected to be passed over such large distances, the results were quite remarkable as shown in Table 2.3. Such vibration levels at distances in excess of 80m were caused by the magnitude of the hammer used, a Hera 8800 diesel, and the river bed being an excellent conductor for the vibrations. To complicate matters, the tubular piles themselves could have been resonating and adding to the vibration levels. To monitor the vibrations at the piers, special brackets were welded to the side of the tubular piles and the geophones were securely held with sandbags.

These results were used by the contractors concerned to produce a suitable schedule for the piling and casting operations.

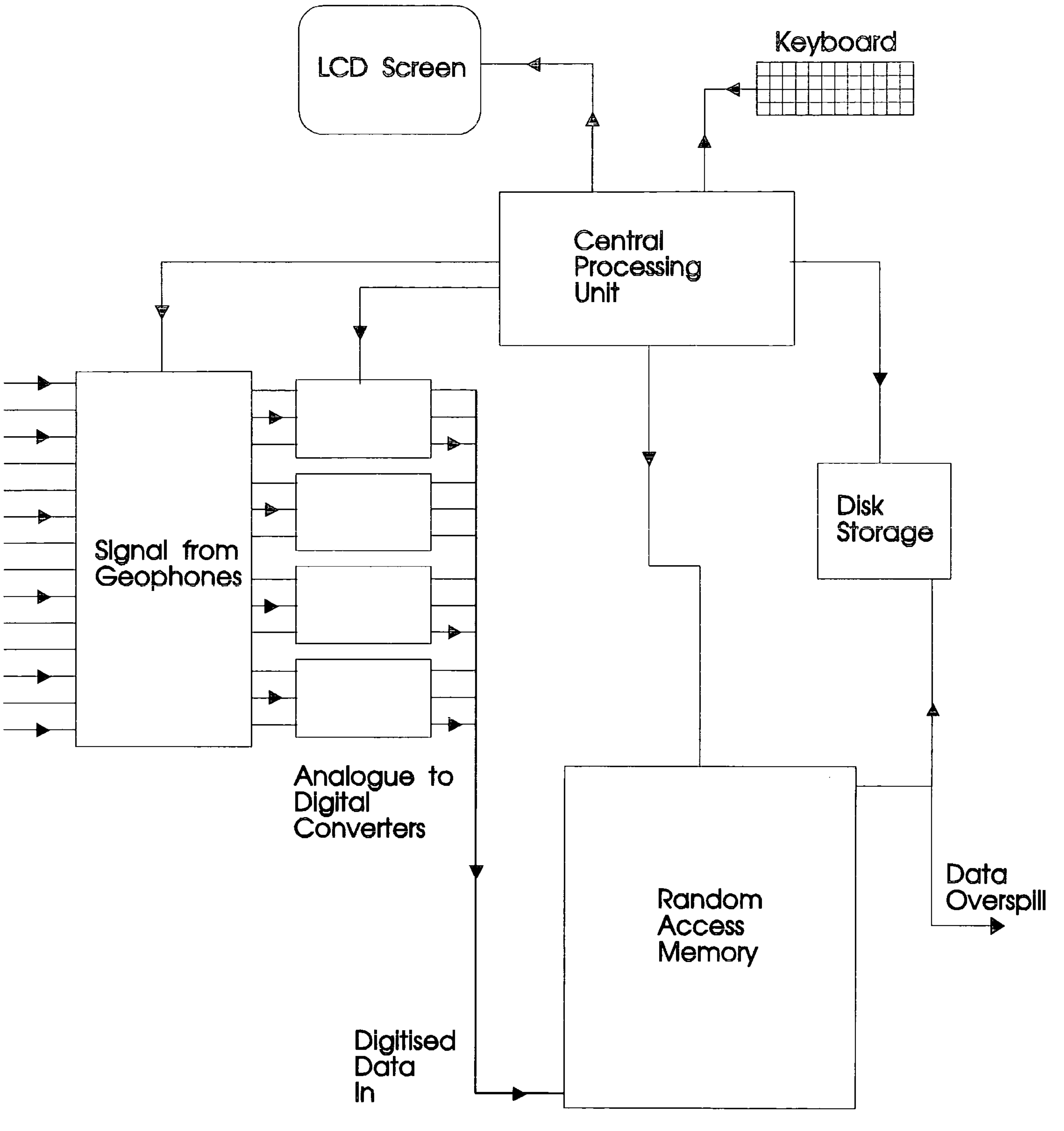


Figure 2.1 - Flow of data through PDR2

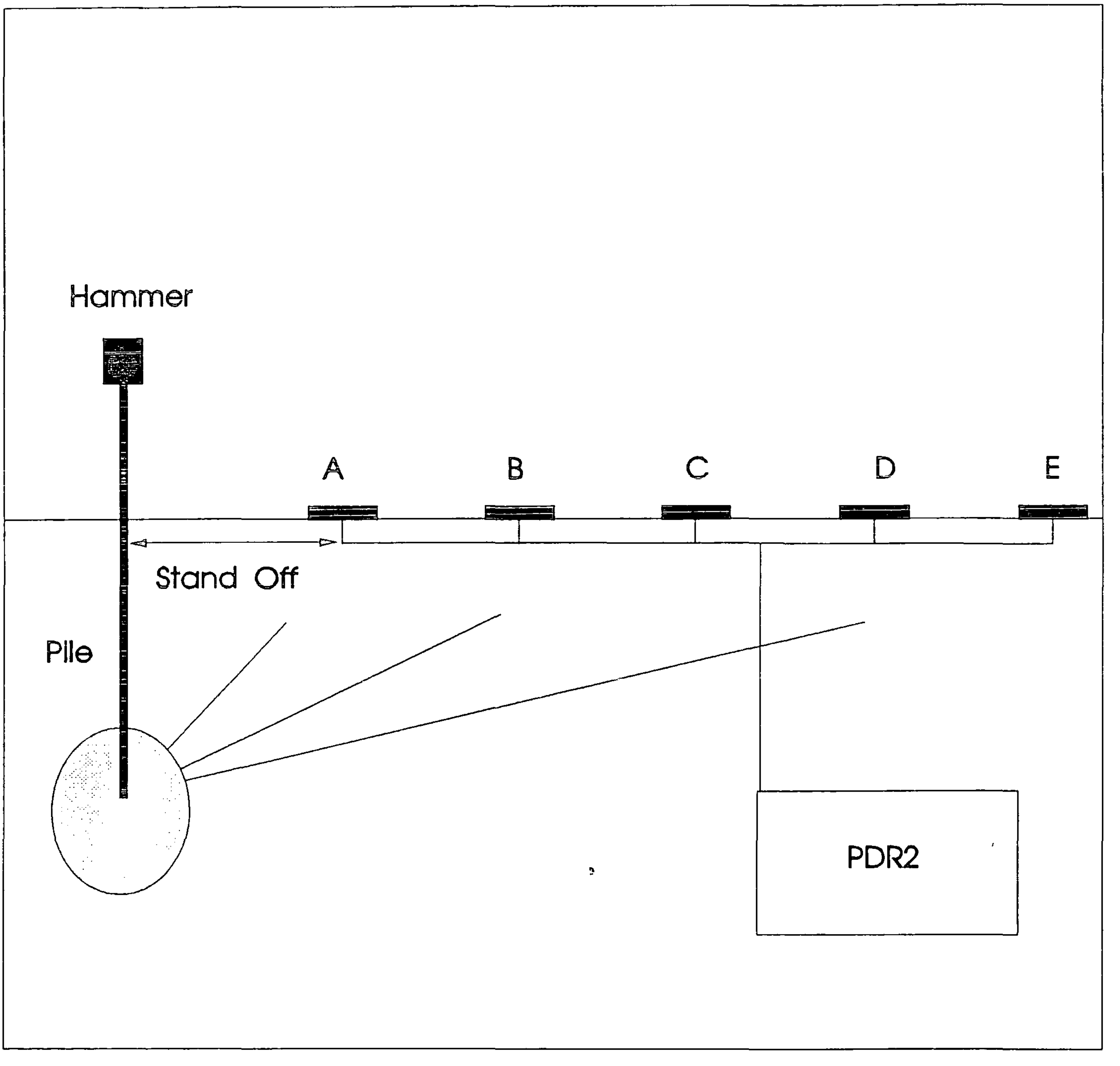


Figure 2.2 - Site Geophone Layout

Date	Time	Location	Disc	File

Ground Condition	
Ground Surface	Subsurface

Pile		
Type	Dimensions	Length

Hammer		
Type	Weight	Drop H.

Geophones Stand-off				
A	B	C	D	E

File	Depth	Comments
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		

Figure 2.3

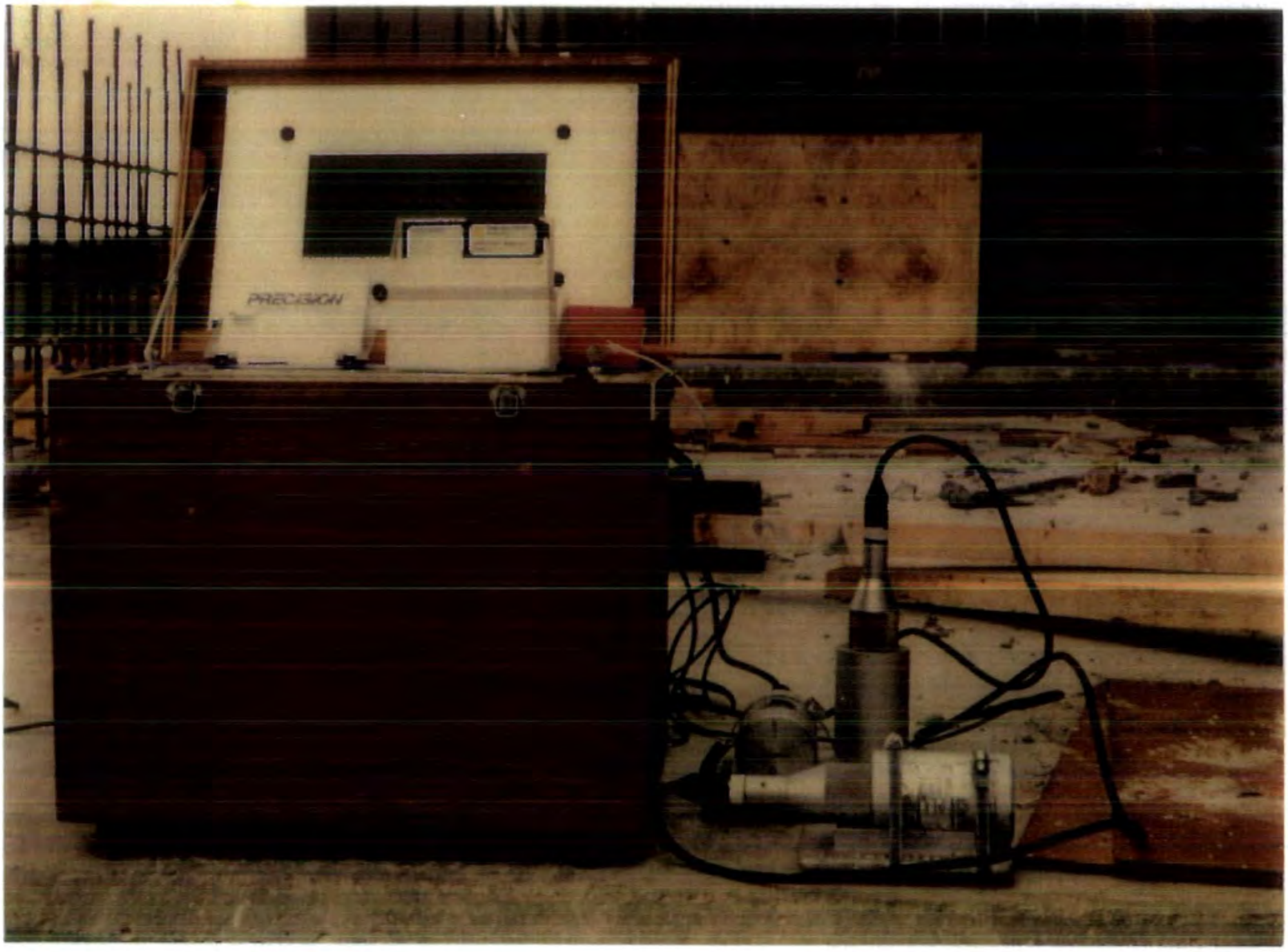


Figure 2.4

Equipment layout showing 3 axis orientation of geophones

ACCELERATION

ALL CHANNEL MAXIMUM = 8731.5566

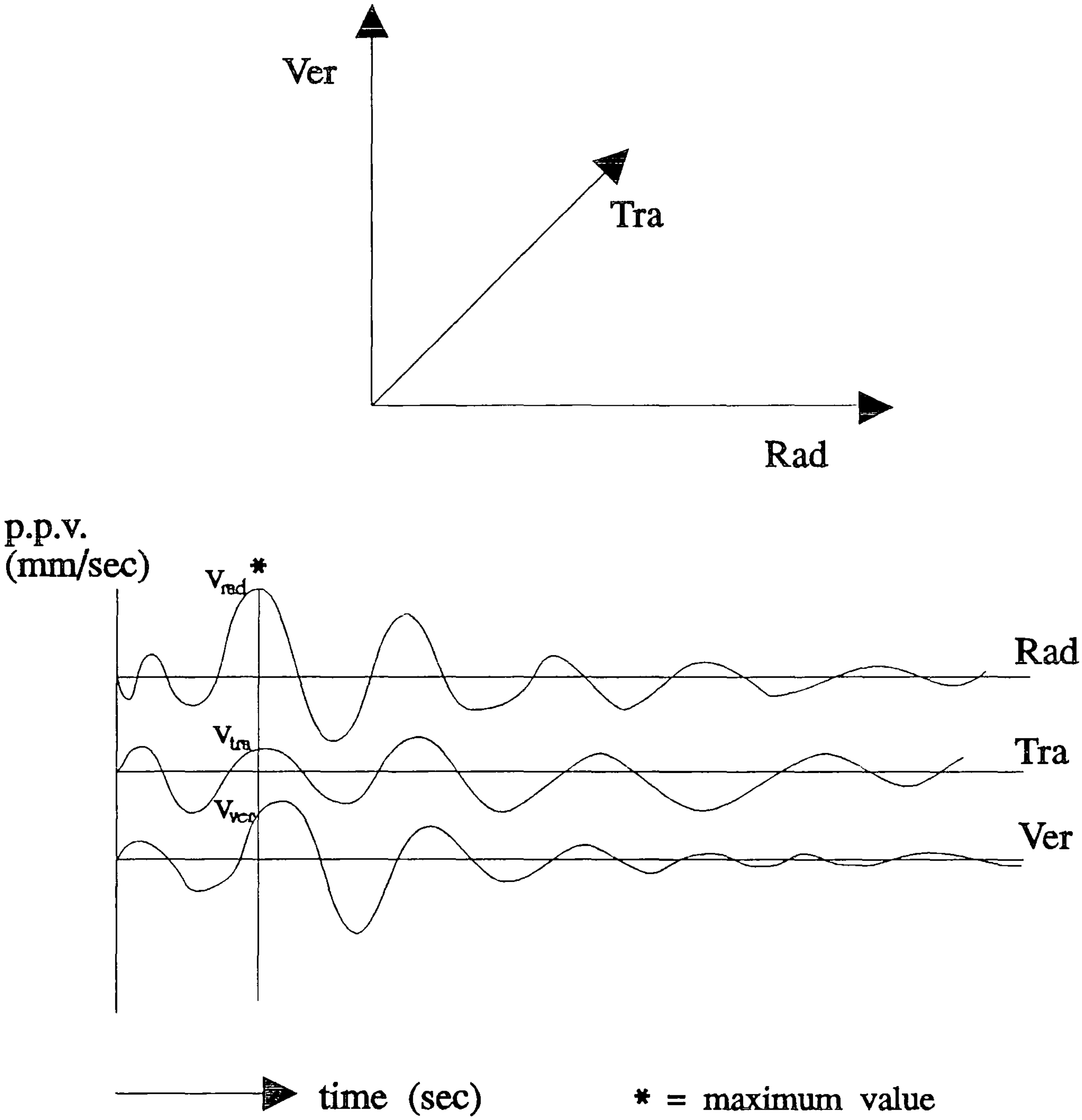
0	4866.1113	.	.	.
1	8731.5566	.	.	.
2	7998.1250	.	.	.
3	2818.1650	.	.	.
4	2607.5137	.	.	.
5	1920.7222	.	.	.
6	242.8750	.	.	.
7	146.6666	.	.	.
8	385.6667	.	.	.
9	137.5000	.	.	.
10	129.0278	.	.	.
11	434.6668	.	.	.
12	75.1667	.	.	
13	141.0140	.	.	
14	139.0278	.	.	
15	0.0000	.	.	

DISPLACEMENT

ALL CHANNEL MAXIMUM = 0.3092

0	0.1421	.	.	.
1	0.3092	.	.	.
2	0.2743	.	.	.
3	0.1125	.	.	.
4	0.1291	.	.	.
5	0.0637	.	.	.
6	0.0092	.	.	.
7	0.0054	.	.	.
8	0.0304	.	.	.
9	0.0116	.	.	.
10	0.0076	.	.	.
11	0.0205	.	.	.
12	0.0025	.	.	
13	0.0093	.	.	
14	0.0123	.	.	
15	0.0000	.	.	

Figure 2.5



Resultant is based upon the time based maximum of the form :-

$$V_{res} = \sqrt{(V_{rad}^2 + V_{tra}^2 + V_{ver}^2)}$$

Figure 2.6 - Description of resultant calculations

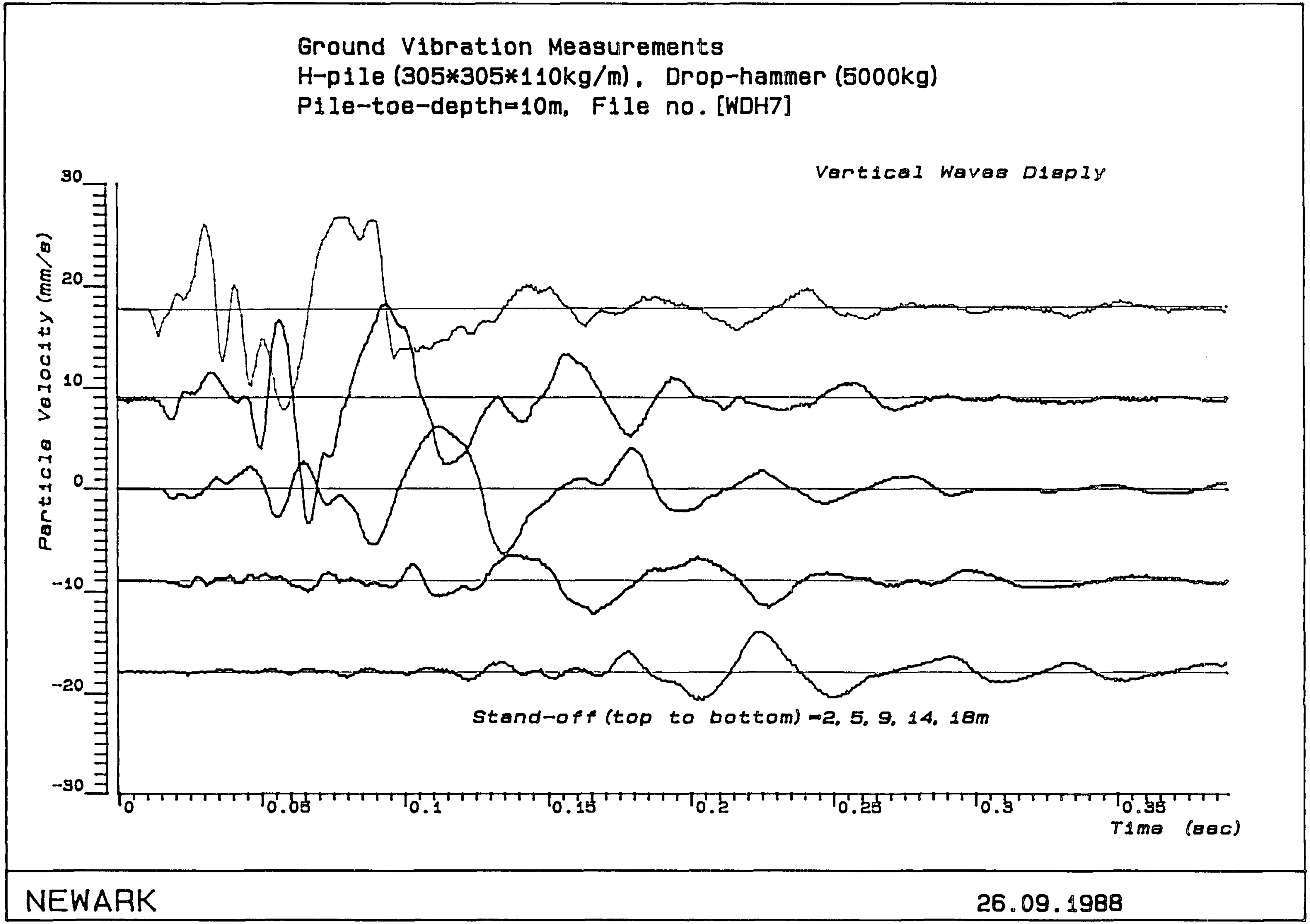

Ground Vibration Measurements
H-pile (305*305*110kg/m), Drop-hammer (5000kg)
Pile-toe-depth=10m, File no. [WDH7]
Vertical Waves Disply
Particle Velocity (mm/s)
30
20
10
0
-10
-20
-30
Stand-off (top to bottom) =2, 5, 9, 14, 18m
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
Time (sec)
NEWARK
26.09.1988

Figure 2.7

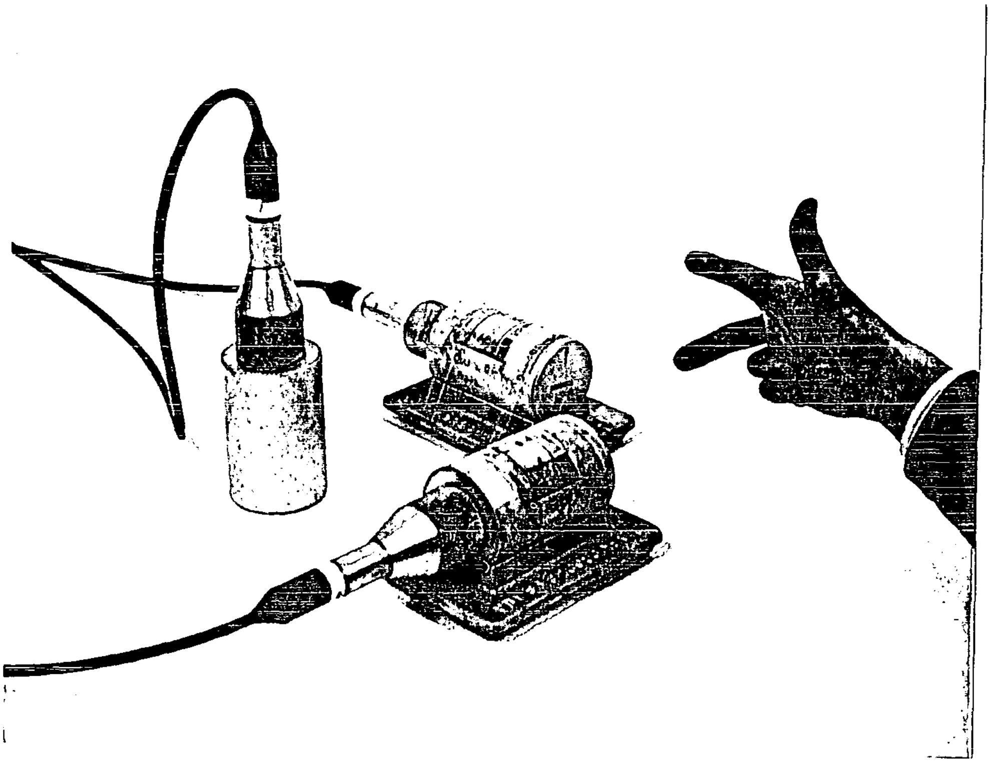


Figure 2.8

Representation of Right Hand Rule

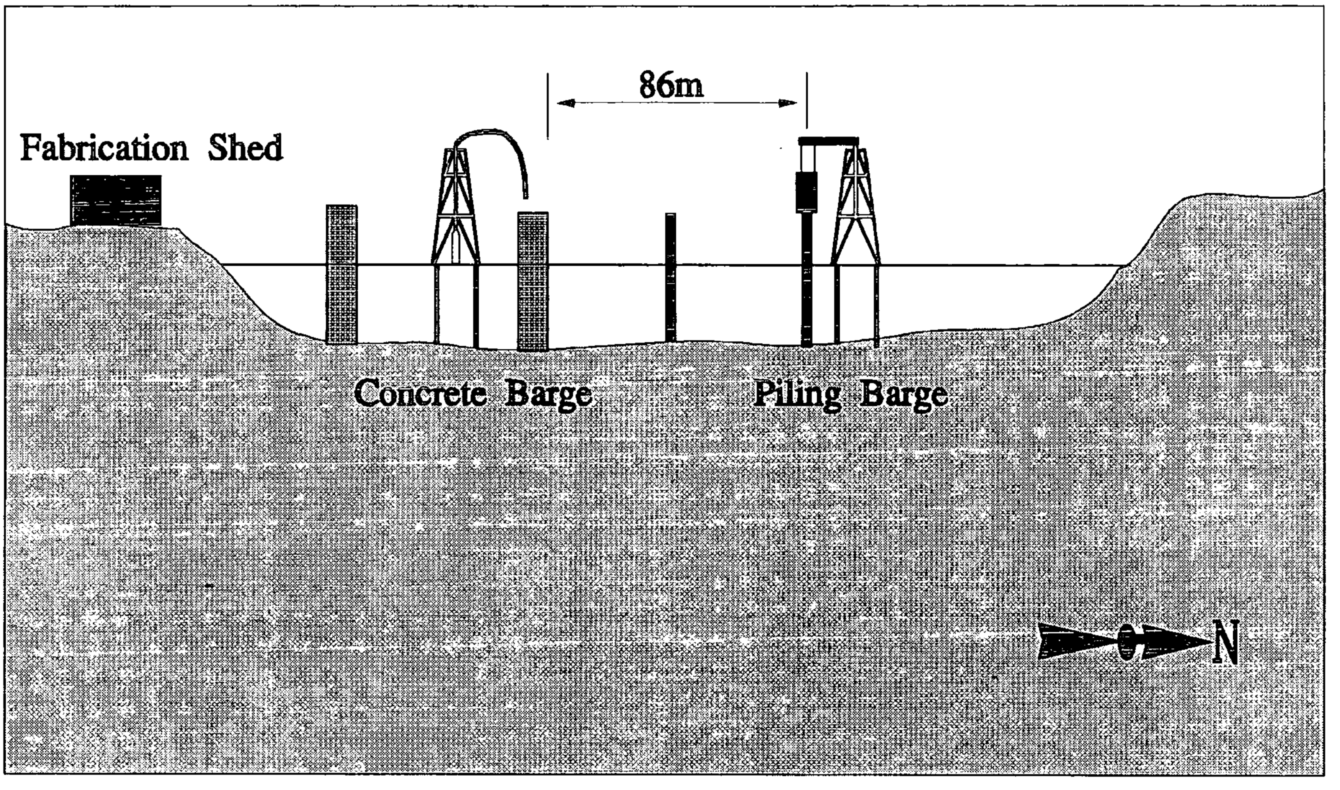


Figure 2.9

Construction of the Dornock Firth Road Bridge

Disc no	Date	File name
PDR2-U	26.09.1988	NDH
Pile		
Type	Dimensions	Length
H-pile	305 × 305 × 126kg/m	12m
Hammer		
Weight	Model	Drop height
5000kg	Drop-hammer (BANUT)	400-800mm

Peak Particle Velocity Measurements ($mm.s^{-1}$)							
File no.	Depth (m)	Geophone-set Stand-off	A 2m	B 5m	C 9m	D 14m	E 18m
N		Radial	18.09	12.80	2.81	1.89	1.84
D		Transverse	5.02	6.10	2.40	1.38	0.80
H	9.0	Vertical	7.73	5.48	2.04	1.46	1.11
6		Resultant	18.74	13.79	3.07	2.14	1.92
N		Radial	16.47	11.52	3.10	1.35	1.84
D		Transverse	6.41	5.24	2.26	1.48	0.80
H	10.0	Vertical	5.87	4.76	2.14	1.46	0.70
7		Resultant	16.67	12.60	3.20	1.88	1.87
N		Radial	19.08	10.51	2.93	2.89	1.48
D		Transverse	6.97	6.86	2.90	1.66	1.07
H	10.5	Vertical	6.45	5.48	3.44	1.55	0.80
8		Resultant	19.37	11.86	4.32	2.93	1.54
N		Radial	15.03	13.31	8.51	3.43	2.67
D		Transverse	7.06	7.72	3.82	2.40	2.41
H	11.0	Vertical	8.12	5.66	3.76	1.91	3.02
9		Resultant	15.28	14.69	8.99	4.00	3.54

Table 2.1

Ground Vibration Measurements of Road and Rail Traffic

Date - 23/03/88
Location - Reston, South Lothian
Original data held as - DATA-32

All peak particle velocities in mm/sec

Geophone Stand-off (m)	A 3	B 5	C 9	D 12	E 17
Radial	0.65	0.81	0.23	0.46	0.54
Transverse	1.25	0.92	0.24	0.48	-
Vertical	1.21	0.91	1.35	0.81	0.88

Passenger train bound for Newcastle

Geophone Stand-off (m)	A 3	B 5	C 9	D 12	E 17
Radial	0.46	0.81	0.23	0.64	0.63
Transverse	0.54	0.83	0.28	0.48	-
Vertical	0.60	0.82	0.47		0.78

Passenger train bound for Edinburgh

Geophone Stand-off (m)	A 3	B 5	C 9	D 12	E 17
Radial	0.28	0.63	0.06	0.37	0.54
Transverse	0.36	0.37	0.04	0.48	-
Vertical	0.30	0.36	1.07	0.72	0.78

Heavy goods lorry on bridge

Table 2.2

Vibration measurements taken at Dornock Firth

Pier 6 [27th March 1990]

Radial Velocity	=10.05 (8.46) mm/sec
Transverse Velocity	= 7.43 (6.80) mm/sec
Vertical Velocity	= 5.03 (3.52) mm/sec
Resultant Velocity	=10.62 (9.40) mm/sec

Distance from piling = 86m

Measurements taken on brackets welded directly onto the side of the pile (pile partially filled with concrete).

Soil type : gravel

Pier 6 [27th March 1990]

Radial Velocity	= 6.30 (4.98) mm/sec
Transverse Velocity	= 7.24 (6.33) mm/sec
Vertical Velocity	= 7.00 (6.29) mm/sec
Resultant Velocity	= 9.01 (7.94) mm/sec

Distance from piling = 86m

Measurements taken on brackets welded directly onto the side of the pile (pile partially filled with concrete).

Soil type : clay going to gravel

Pier 6 [28th March 1990]

Radial Velocity	=10.05 (8.63) mm/sec
Transverse Velocity	= 7.43 (6.20) mm/sec
Vertical Velocity	= 8.44 (7.57) mm/sec
Resultant Velocity	=11.46 (10.27)mm/sec

Distance from piling = 86m

Measurements taken on brackets welded directly onto the side of the pile (pile partially filled with concrete).

Soil type : gravel

Table 2.3

3 Database

A very large quantity of variable site data has been acquired and a database structure was chosen to allow selective retrieval of site "records". It was decided that peak particle velocities (and accelerations and displacements) from a batch of site records should be described by a polynomial function for interpolation. The coefficients of the polynomial would provide the essential stored information in the database, in preference to storing the massive quantities of raw data. The database was constructed to allow a structured query system. A suite of programs was written to allow organic growth of the database system. This suite of programs allows transfer from logger to PC, analysis and optimisation of raw data, the fitting of data and the filling of the database itself. A shell program was written to allow both experienced and novice users to extract information.

The various interactive elements of the database which combine together to form the system will be described in the following order :

* The fitting of the site data
* The structure of the database
* Data Analysis
    * Optimisation
    * Filtering
    * Transfer
    * Back-up
    * Analysis/Preparation for fitting
    * Fitting
    * Storage
* Data Handling

3.1 Fitting the vibration data

The case for data storage of all of the raw site records, allowing access to a full account of the actual data recorded on site, is very poor. Whilst this facility allows for total historical accuracy, the actual precision of site data is often low and the variability high. Construction sites are dirty open-air work-places, where much of the work is on a one-off basis. Any large scale project inevitably leads to some variability of working practises and standards. Piling frames are not as tight as they could be, the hammer is not always held totally vertically above the pile, hammers are not always running at their maximum efficiency and so on. This is an indication that the data collected will suffer inherent variabilities.

Mathematical modelling of the data by polynomial equations may eliminate erroneous points or compensate for minor errors. Also the problems of the mass storage of large quantities of data for each record, which cause major problems for system performance, can be avoided.

The modelling system employed must describe every component (Radial, Transverse, Vertical and Resultant) of velocity, acceleration and displacement - essential for academic purposes.

The description of each record is then simply a series of computed polynomial coefficients, which can be applied to the appropriate equations to reproduce the levels of ground vibrations, not just at the measured stations, but by interpolation at close intervals throughout the range (usually 2m to 20m from the pile).

When deciding upon a suitable fitting system, the true variance of the data became apparent. Attewell and Farmer (1973) had utilized a logarithmic approach, which was well suited to large quantities of data. However, for the database, an accurate representation was required of the levels of vibration which had occurred at the site in question. Moreover, the database was to provide a "worst case" view of the events at the site, which describes the most severe ppv's (peak particle velocities), rather than a mean or average. By adopting this methodology, the database will offer realistic maximum levels of vibration that were recorded. To this end, only the maximum values of individual channels were passed to the system.

For one record of the database, it was required to model all movement types over all four components, as previously stated. As the majority of site visits employed only five sets of geophones, five data points would be the sample size to be fitted in each case. This small sample size led to statistical problems in regression analysis.

Several fitting systems were considered, the main modelling techniques tested being:

* Linear
* Logarithmic
* Quadratic
* Cubic

Also, the following mathematic methods were applied to these modelling types:

* Upper bound
* Mean
* Combination of 4 point fit plus interpolation.

Examination of the data to be fitted (Figures 3.1/3) showed that the data could vary from near linear to cubic. A general trend could be represented by the graph shown in Figure 3.4. The typical curve can be seen to have two inflections, one concave and one convex; this implies the use of a cubic for an accurate model of the system.

A good fit for this general trend can be seen to be a cubic polynomial. However a 4 point fit plus linear interpolation also seemed plausible. This system is a combination of a linear relation between the first two points and a polynomial for the remaining four. Whilst this would lead to difficulties in computational storage, it initially appeared to offer the best solution. However, on carrying out many random tests on the site data it became obvious that fitting a polynomial to four points could produce some very poor results. A logarithmic approach was also tested for the remaining four points, but this could not account for any rise in the tail of the graph, a common occurrence as seen in Figure 3.4. Consequently this four point fit plus linear interpolation system was rejected.

The best solution proved to be cubic least squares fit, providing a mean solution that could react to the majority of cases to be modelled. As previously stated, the data to be modelled is of small sample size and large variance - a system that could fit all cases was never envisaged. The cubic fit provided the best of the available options. Examples of the precision of fit are shown in Figures 3.5/7.

3.2 Data Structure

When the structure of the database was being considered, at all times the end product had to be borne in mind. The database would essentially have two main users - British Steel, the joint sponsors, and the students and members of the academic staff at Durham University Applied Mechanics Group. While both parties had some common aims, there were several areas of diversity.

Both parties required a system that allowed historical data to be interrogated selectively to aid the user in understanding the levels of vibration recorded in response to differing piling systems. They also wanted a comprehensive record of vibrations at the sites visited. In addition British Steel hoped to use the system to help them in solving specific piling problems they encountered. The vibrations caused by the driving of steel piles can cause worry to residents of neighbouring properties and in severe cases can even inflict superficial damage to those properties. Customers of British Steel often enquire about the expected level of vibration associated with a particular piling system if they envisage a problem.

If a system could assist them to advise on the levels of vibration likely to result, then this would be of real benefit. With access to a large pool of historical data, specific questions could be asked and examples extracted that matched these criteria. The levels of vibration recorded at these locations could guide the user of vibration equipment on expected levels. Durham University also wanted a comprehensive system of data storage that would allow accurate analysis of the data. This analysis could form the basis for investigation into the main factors that affect the level of ground vibrations. This information is obviously of use in trying to limit future vibrations.

These various aspects of the project had to be combined into a system that could respond to the needs of both parties.

The database had to store as much data per record as was available through analysis (ie radial, transverse and vertical components of acceleration , displacement and velocity and the resultants of these). Also the dominant frequencies should be stored. Each record within the database had to contain sufficient descriptive information uniquely and clearly to define each record. However too many descriptive fields would lead to slow database performance. These descriptive fields had to be designed in such a manner as to be conducive to structured query routines.

3.2.1 Data Optimisation (Toe Depth)

Some grouping criteria were required which guaranteed data integrity but precluded the data duplication previously mentioned. Actual site experience led to examination of the effect of toe depth on the magnitude of recorded surface vibration levels. If records were grouped together at reasonable levels of toe depth a compromise could be reached between depletion and duplication. On-site measurement of toe depth is often difficult because the piles are rarely marked. Estimation to within a metre could be made but this would still lead to many records and possible duplication. The final decision was taken to group the records of any one site into bands of 5 metres i.e.

Toe Depth	Range (m)
A	0 - 5
B	5 - 10
C	10 - 15
D	> 15

This system gives sufficient flexibility to the operators in allowing them to chose the depth range most suitable to their requirements, whilst ensuring data integrity.

3.2.2 Database Descriptor Fields

The database was built around 24 alphanumeric descriptor fields of which several could be used for selection (see 3.4). There follows a description of each of the fields. The symbol * identifies those fields available for selection.

1 Record Number *

This is a computer-generated sequential number unique for each record. This allows any record to be recalled at any time. This number also reflects the sequence in which the records were placed in the database.

2 Disc Code

This code allows the original data for the particular record to be easily traceable. (The DATAnn refer to PDR1 data which necessarily means that there is no associated acceleration or displacement data for that particular record. The earlier generation recorder/processor, PDR1, was not capable of producing this information and the two machines were not compatible.)

3 File Code

This allows the individual files to be recognized on the disc traceable from the disc code. As several files were recorded per record and then these records were subsequentially optimised, there is no means of telling from which individual files the data emanated.

4 Investigation Date

This is the date on which the actual site data was recorded.

5 Site Location (1) * and

6 Site Location (2)

These are the global and local locations of the site which the record represents.

7 Hammer Type *

The generic type of hammer used:

Drop

Hyd Drop

Vibrodriver

Jacked Vibrodriver

Air

Diesel

8 Pile Type *

The generic type of pile being driven:

Larssen

Frodingham

Concrete

Tubular

H Pile

9 Ground Type *

The type of ground being piled, is described by a field containing up to twenty alphanumeric characters. Due to the artificial dividing up of the ground into 5m bands (see section 3.2.2.11), a full description cannot be given in twenty characters. Also, to give a full description would require a detailed borehole report, but this was simply not available at the majority of the sites visited. A system was adopted whereby the most dominant known soil type was placed first with any other present soil type secondary. Capitalization of either primary or secondary soil type infers dominant strata of that type. If further details of the soil profile are known they can be included in the comments fields.

10 Classification *

This is the condition of the dominant soil type e.g. firm for clays, dense for a granular soil. The capitalization referred to in the soil type also applies for classification.

11 Toe Depth *

As mentioned in 3.2.1, for ease of data representation the ground is split up into 4 theoretical layers. Accordingly, if a toe depth is described as B, this means literally that the data used to produce that record were all recorded whilst the toe of the pile was between 5m and 10m deep.

12 Comments 1

13 Comments 2

14 Comments 3

15 Comments 4

16 Comments 5

These fields contain additional information which, whilst pertinent to a record, does not fit into a specific field or is additional to the information in a field. Borelog reference numbers, contact names and addresses can all be stored in this field.

17 Hammer

This is a duplication of field 7. It is needed because the database is viewed on two separate screens and unfortunately SmartWareII, the software package (Section 4.3), does not have the ability to duplicate fields automatically.

18 Hammer Model *

This contains the description of the hammer model used. The field is large enough to hold the names of any of the hammers currently available.

19 Nominal Energy (kJ) *

This is the nominal energy imparted into the top of the pile. It must be stressed that this is the NOMINAL energy and therefore takes no account of the relative efficiency of the hammer. It also can take no account of the relative efficiency of each hammer blow, the efficiency of the hammer/pile interface and the difference between vibrodrivers and impact hammers.

20 Set (mm)

The amount of penetration of the pile per hammer blow. This data was not always available for each site visited. For continuous hammers (vibrodrivers) and some high frequency air hammers, this figure represents the amount of penetration for a given time period.

21 Pile

This is a duplication of field 8. It is needed because the database is viewed on two separate screens and unfortunately SmartWareII does not have the ability to duplicate fields automatically.

22 Pile Section *

This is the section of the pile being driven.

23 Pile Length (m) *

This is the length of the pile being driven.

24 Rake *

This signifies whether or not the pile being driven was raked. If this field is positive, the angle of rake will be held in the Comments (5) field.

3.2.3 Database Coefficient Fields

There are four coefficients that describe the cubic equation for each component of each vibration type, making forty eight in all for each piling activity within a band of toe depth. These coefficients are held as floating point decimals to an accuracy of 3 decimal places, and Table 3.1 shows examples of these coefficients.

3.2.4 Database Presentation Screen

On the main screen of the database (the top screen), there is a summary table which lists the resultant velocities at five distances, Figure 3.8 shows this initial screen. This requires that there are an additional ten fields held in the main datafile. The distances are described as Stand Off distances. The stand off is the horizontal distance from the point where the pile enters the ground to where the vibration is being measured.

Five fields are used to hold the summary stand off data, the first and last being the actual values, while the other three are calculated as equidistant. This choice was due to computational difficulties in transmitting the original data. However its final effect is very suitable as the equidistant spread gives a good view of the attenuation. The velocity values for each of the stand-offs are calculated from the cubic polynomial coefficients associated with the model for the resultant velocity fit. The unit for all the velocities quoted is mm/sec.

3.3 Data Analysis

The amount of raw site data acquired during the period of the ground investigation project was large, since, as noted earlier, approximately 130 separately identifiable site visits were made throughout the UK. Initially any suitable site was visited. However in the later stages efforts were made to try and cover the range of differing soil types and piling systems. This ensured that the database would cover a wide range of combinations, subject of course to physical and economic limitations.

In the initial stages of data analysis the method of subdividing the data was of key importance, since simply including every record of every site visit would lead to unnecessary duplication. Conversely, if too many records were discarded then important data could be missed. Obviously every site had to be included, but it was not uncommon for over 30 separate data files to be taken at any one site.

3.3.2 Initial Filtering

Prior to the first-stage optimisation, initial filtering was carried out on PDR2 by visual inspection. Any errors at this stage could be dealt with, these usually falling into 3 distinct groups :-

1) Base line correction. The signal had wandered from the calibrated baseline during signal capture, thereby giving a misleading result. A simple correction to the calibration file ensured that accuracy was maintained.

2) Digital filtering to remove noise on the signal. Electronic noise from any source occasionally caused spikes on the signals - these spikes may be removed with a filtering routine on PDR2.

3) Flat signal, malfunction at site. This occurred infrequently and effectively rendered the record non-usable. It was a result of partial equipment failure, usually at the geophone or connection, leading to an open-circuit condition.

3.3.3 Data Transfer

Once the data had been pre-screened on PDR2, the selected files were transferred to a Nimbus AX personal computer. Four files were transferred to represent one event at one particular site and generic forms of these files are shown in Figure 2.5. These files contained all the velocity, acceleration and displacement data for that particular record.

Files were transferred in batches and named accordingly, so ensuring that the raw data was identifiable at every stage of analysis. The data was sent serially in the form of an ASCII file and captured on the Nimbus using the communications package Procomm. This package captured the data and saved it directly to disk, whilst also showing the captured items on the screen. This allowed visual checking to be carried out at this stage, which was important as serial lines can themselves pick up noise and are liable to data corruption. To prevent this occurring, a large smoothing capacitor was fitted to the mains supply of PDR2.

3.3.4 Floppy Disk Back-up

Data passed to the Nimbus were placed directly onto a 3.5" floppy disc. This allowed a permanent copy of the raw, transferred data to be stored, for further analysis or as a back-up.

3.3.5 Data Analysis / Preparation for Fitting

Analysis was carried out in batches, the operator identifying which records were to be used, locating the data disks on which these sites were represented and then copying these files to the relevant sub-directory on the Nimbus. Using the banding of toe depths, a certain amount of work had to be carried out to ensure that the correct files were chosen for a particular record.

A suite of programs was written which allows a non-experienced user to analyse site data and build up the database. Listings and brief descriptions of these programs are included in Appendix 2.

Initially the data were removed from the ASCII file and placed into a transfer database. This removal was carried out using a simple automated routine which relies on the data always being in the same format. Unfortunately, PDR2 had a slight problem in sending data in a constant format, so the program contained routines to ascertain the precise format being sent.

Once a file had been transferred the user was prompted to input the associated stand off distances for that particular file. In some circumstances, the usual order of the geophones was changed for a particular site; an alphabetical routine was capable of accommodating this.

Once all the files that were to make up a single database record had been loaded into the transfer database, they were optimised. There was no limit on how many files could be combined to construct one record. The optimisation routine sorted the data into the correct order and then chose the largest value for each channel and movement types. If eight different files had been taken at one site in one toe depth range, the optimisation routine produced a maximum file representative of all of them.

The data were re-sorted into a preset format and then the fields required were transferred across to the spreadsheet module of SmartWareII. The integrated approach of SmartWareII was of particular advantage in this respect.

3.3.6 Data Fitting

The cubic least squares system described in Section 3.1 is simple in its mathematical concept, but requires matrix manipulation. The equations are shown in Appendix 3.

In order to carry out the curve fitting two spreadsheets were used. The first received, formatted and named the appropriate data ranges and the second called in the named ranges and then processed the calculations. This method allowed total automation of the process.

The second spreadsheet was laid out in such a manner that any stage of the fitting could be examined easily. The original data were situated in the upper left corner and directly below was the stand off data. Below that were the power calculations required of the stand off distances, and below them the combined power calculations required for the least squares fit.

All the components of the movement types were calculated at once, leading to twelve sets of 3rd order equations to be solved. A matrix solution by Gauss-Jordan elimination was used, as shown in Appendix 4.

A graphics routine was incorporated into the fitting system that allowed the accuracy of fit to be examined. This allowed the user to identify any process problems whilst checking the precision of fit.

If the fit was good then the coefficient data was correctly formatted and then sent across to the database module for inclusion into the main ground vibration database.

The whole fitting process was menu driven and automated. This represented a major labour saving process and contributed significantly to the overall performance of the project.

3.3.7 Data Storage

Once control was returned to the database module the coefficient data was automatically placed into the next available blank record in the GV Database. The user was then prompted to enter the appropriate alphanumeric data which uniquely described the record.

3.4 Data Handling (DMM)

SmartWareII's database module contains powerful commands driven by menus at the bottom of the screen. The quickest way to extract useful information from the GV Database is by direct communication to the data through these menus. However this requires a good working knowledge of SmartWareII, an understanding of database techniques and a level of computer literacy.

In an attempt to enable non-expert computer users rapidly to access the data, a simple, user-friendly operating shell was written. This shell was written in SPL (SmartWareII Programming Language), a powerful structured language not unlike C.

3.4 Operation

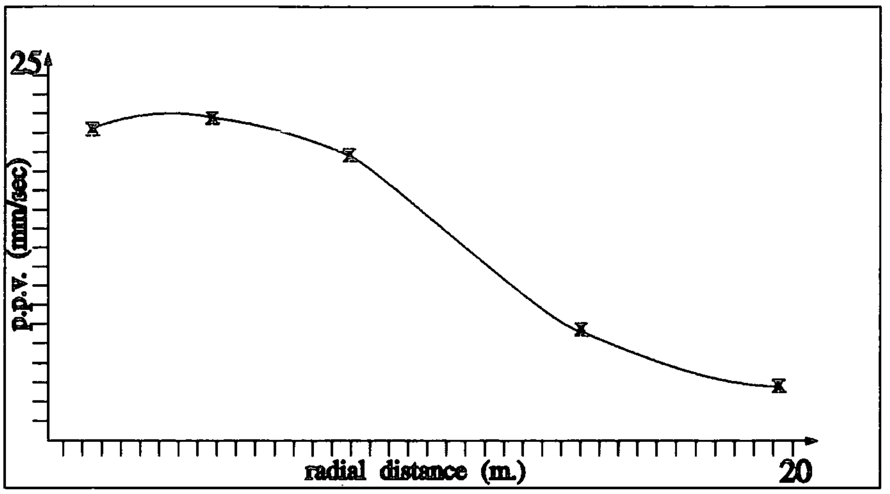
The program allows users to build up specific queries on 12 of the database fields and then view or print the data selected. Figures 3.9/11 show the program in use. The queries that are built up may be supplemented or modified in any way. Queries are made simple initially to gain an idea of the number of suitable records and the query may be made more specific if further selection is required. A full listing of the documented program is contained in Appendix 5. A user manual is also available for the system.

Basically the user selects a field on which to query the system from a displayed menu, and the system then prompts the user for a value for that field. The user may structure a query on any of the following fields:-

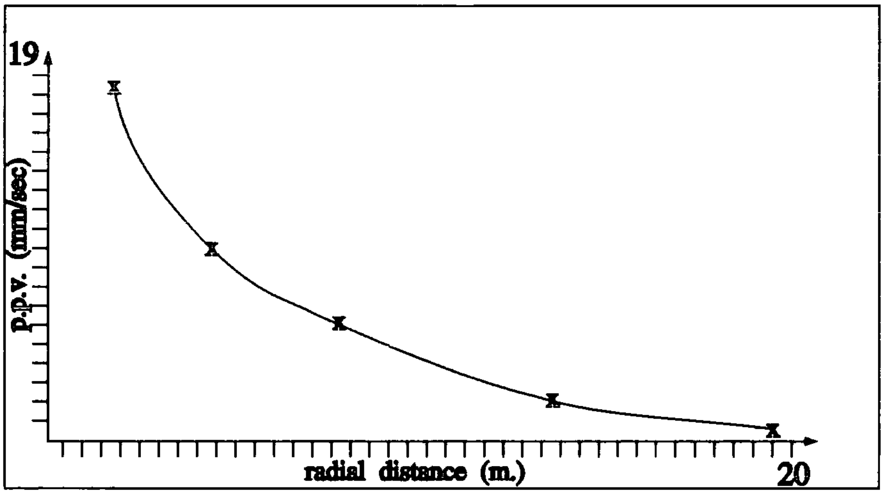
Site Location	Hammer Model
Pile Type	Nominal Energy Input
Pile Section	Ground Type
Pile Length	Ground Condition
Rake	Toe Depth
Hammer Type	Record Number

For any numerical field, except record number, the system automatically searches the database over a range - with the specified number as the centre of that range.

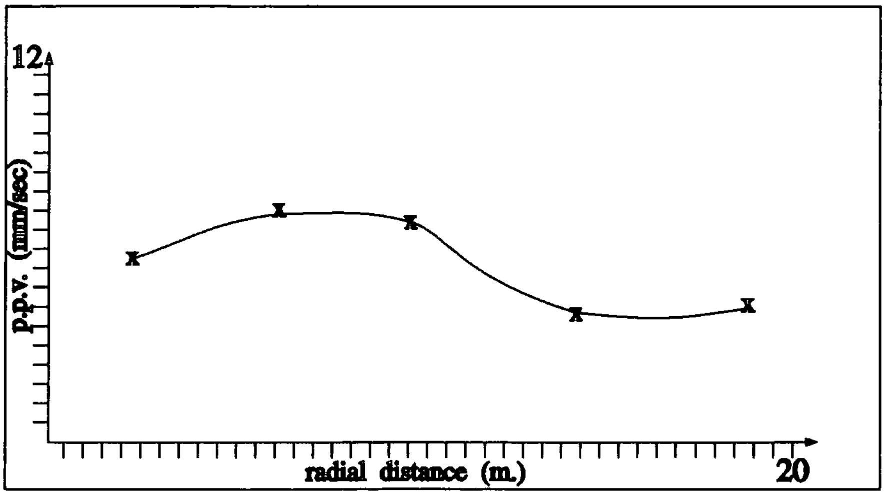
Once the system has responded with an answer to a specific query, these selected records may be viewed - either as a one line summary or the full record (Figures 3.12/13). A full tabulation of the velocity (acceleration or displacement) can be produced on screen, describing the movement in radial, transverse, vertical and resolved components. These tables may be printed in draft or enhanced format from within the system. A sample of the output is shown in Appendix 3.



Bearing Pile, Diesel hammer, Dense granular soil, toe depth C



Sheet Pile, Vibrodriver, Loose PFA, toe depth D



Bearing Pile, Vibrodriver, Stiff clay, toe depth D

Figure 3.1/3
Examples of velocity attenuation

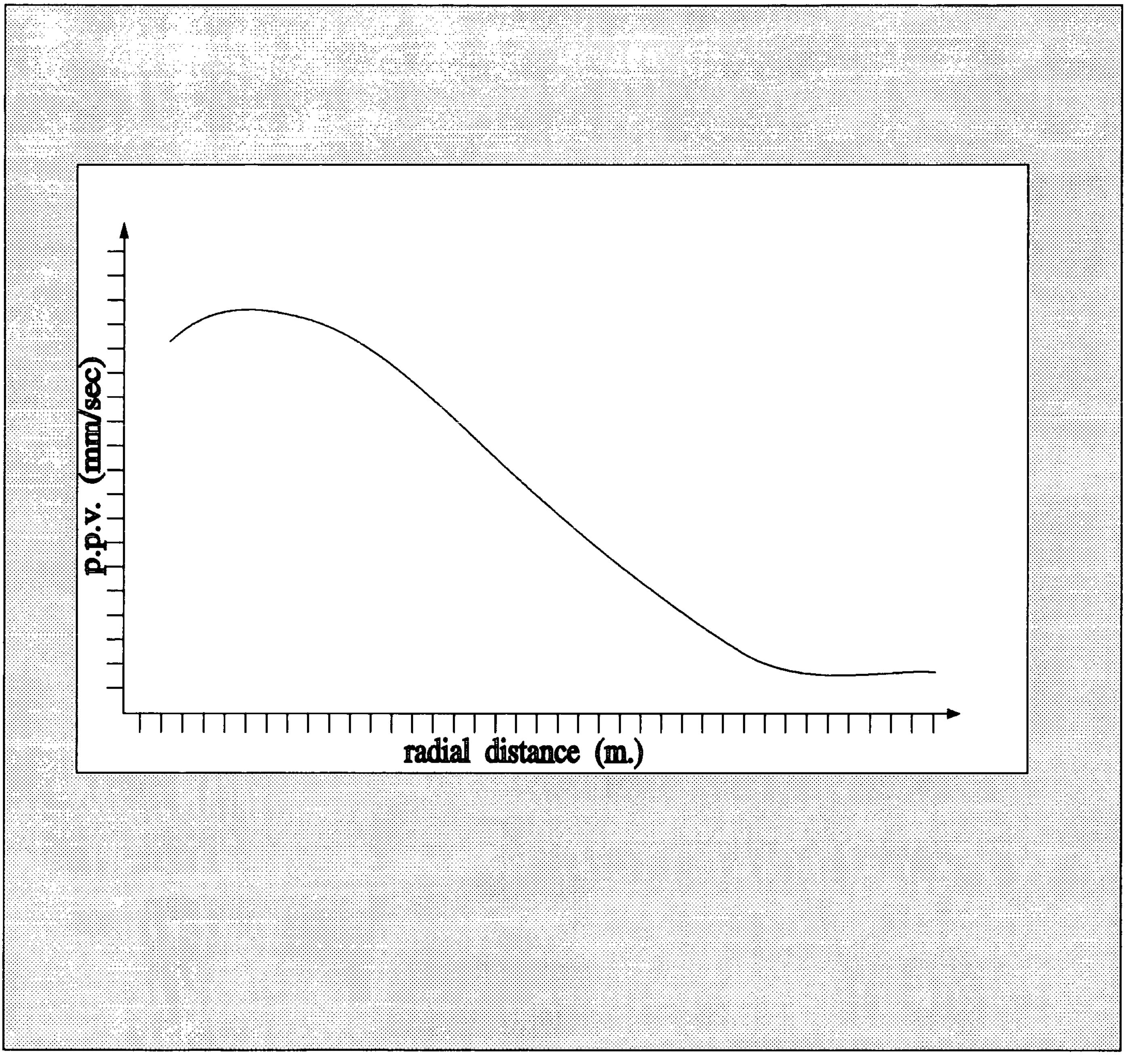
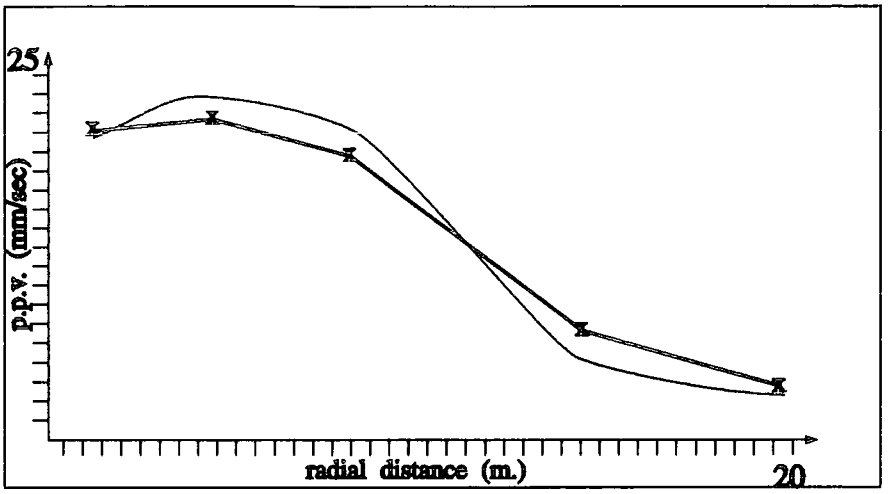
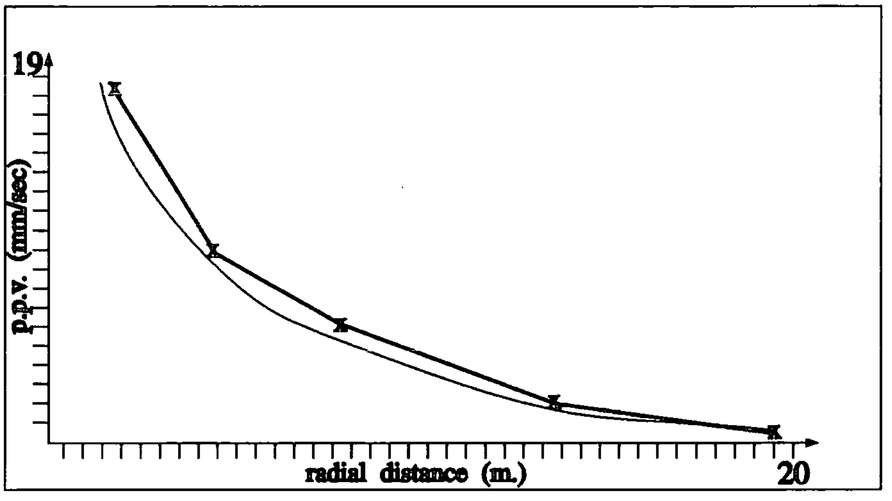


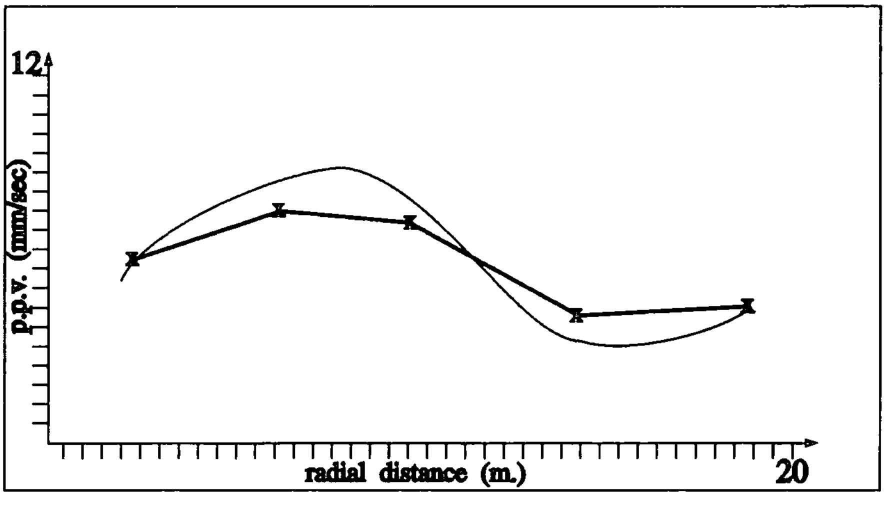
Figure 3.4
General trend of velocity attenuation



Bearing Pile, Diesel hammer, Dense granular soil, toe depth C



Sheet Pile, Vibrodriver, Loose PFA, toe depth D



Bearing Pile, Vibrodriver, Stiff clay, toe depth D

Figure 3.5/7
Examples of precision of fitting process

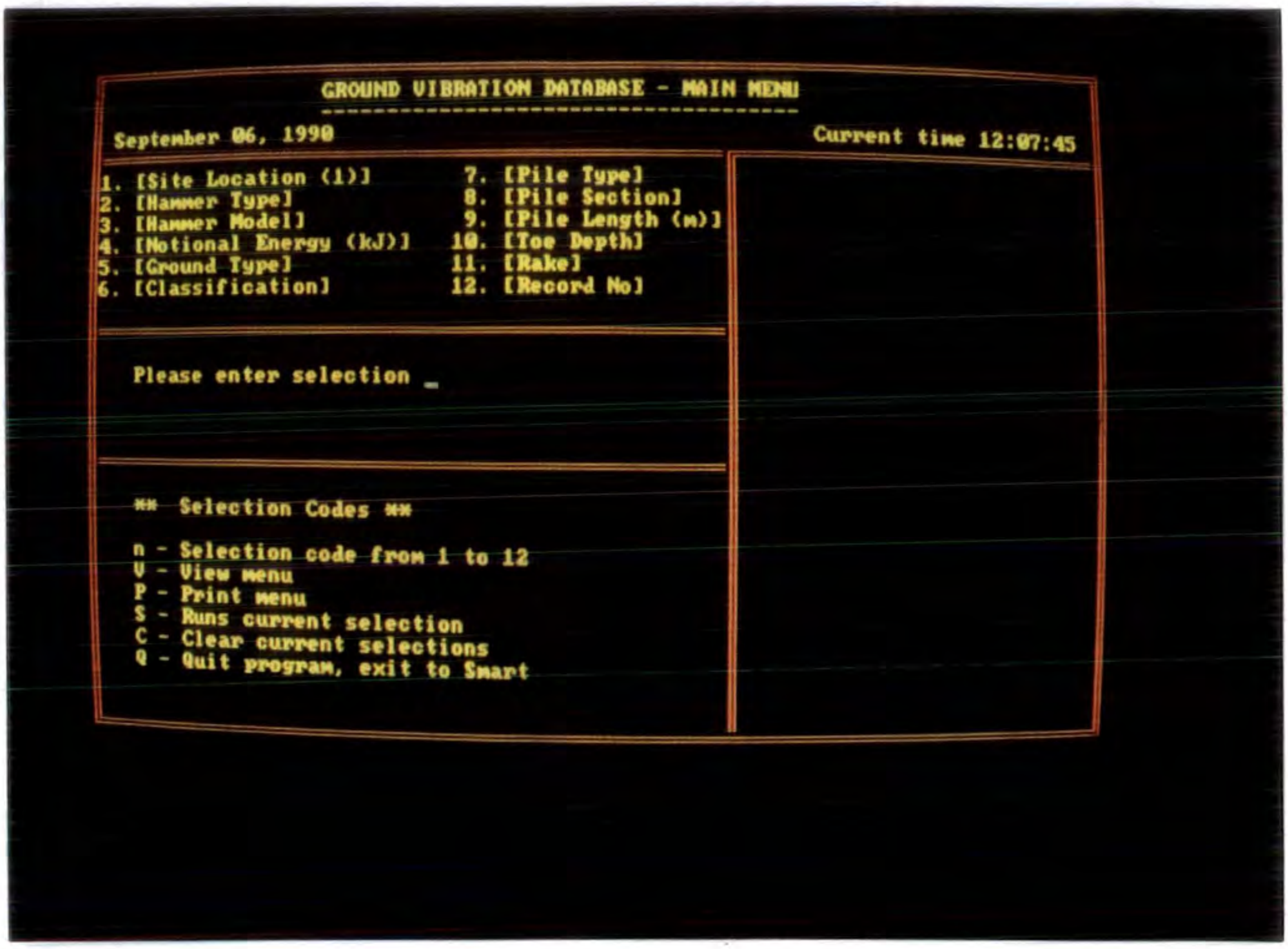
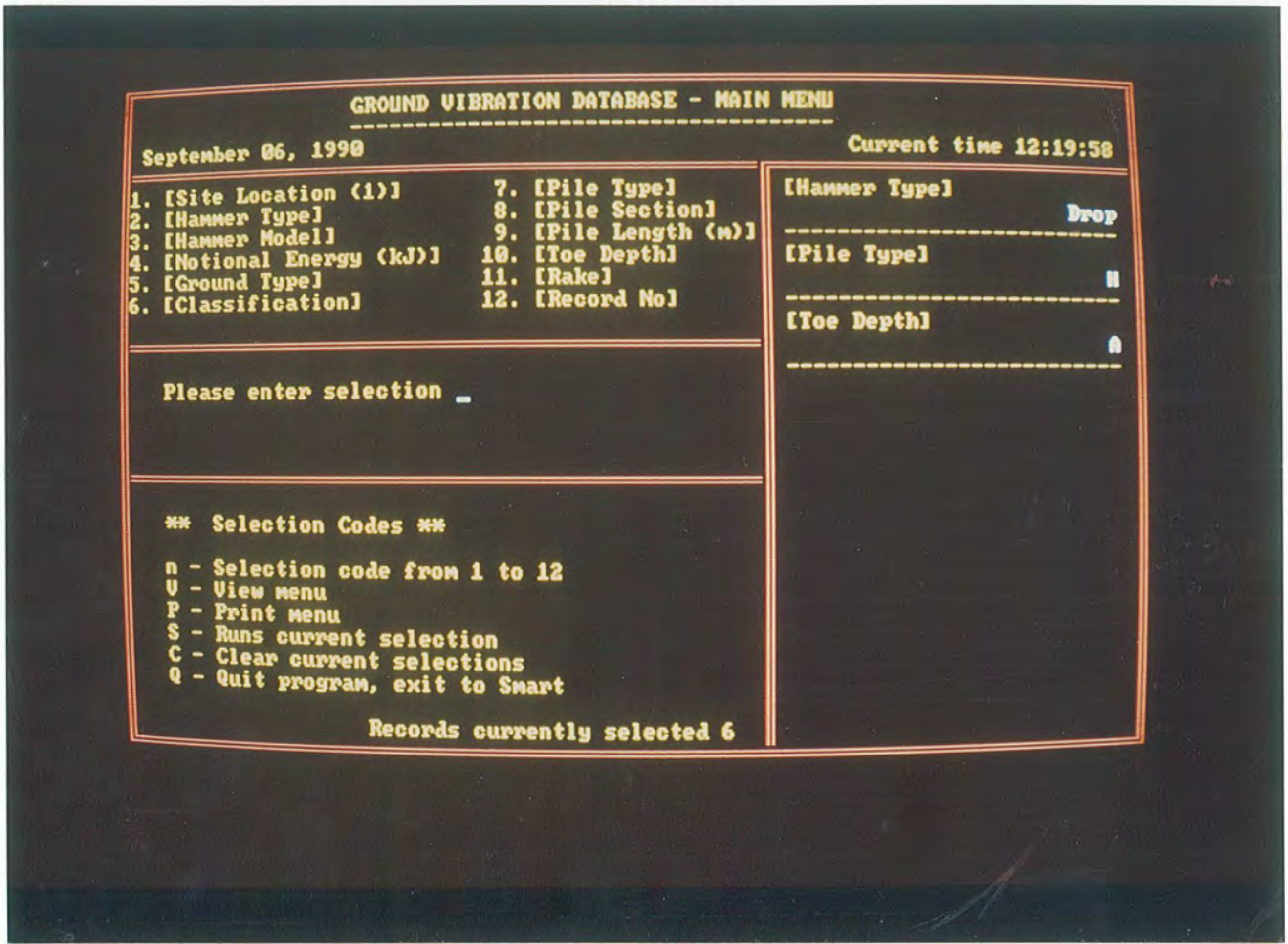
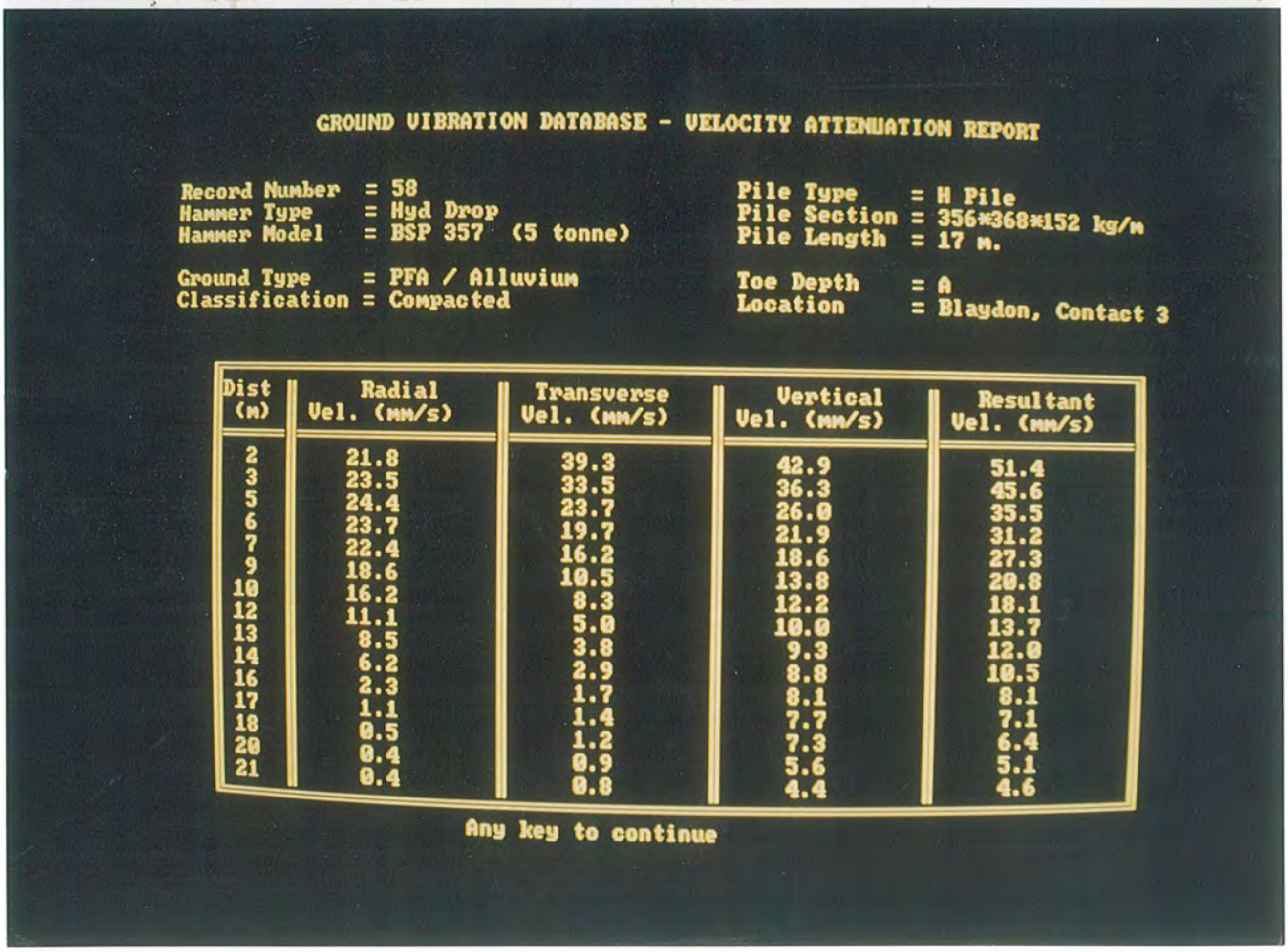


Figure 3.8

Initial screen of DMM database program





GROUND VIBRATION DATABASE - VELOCITY ATTENUATION REPORT

Record Number = 58
Hammer Type = Hyd Drop
Hammer Model = BSP 357 (5 tonne)

Ground Type = PFA / Alluvium
Classification = Compacted

Pile Type = H Pile
Pile Section = 356*368*152 kg/m
Pile Length = 17 m.

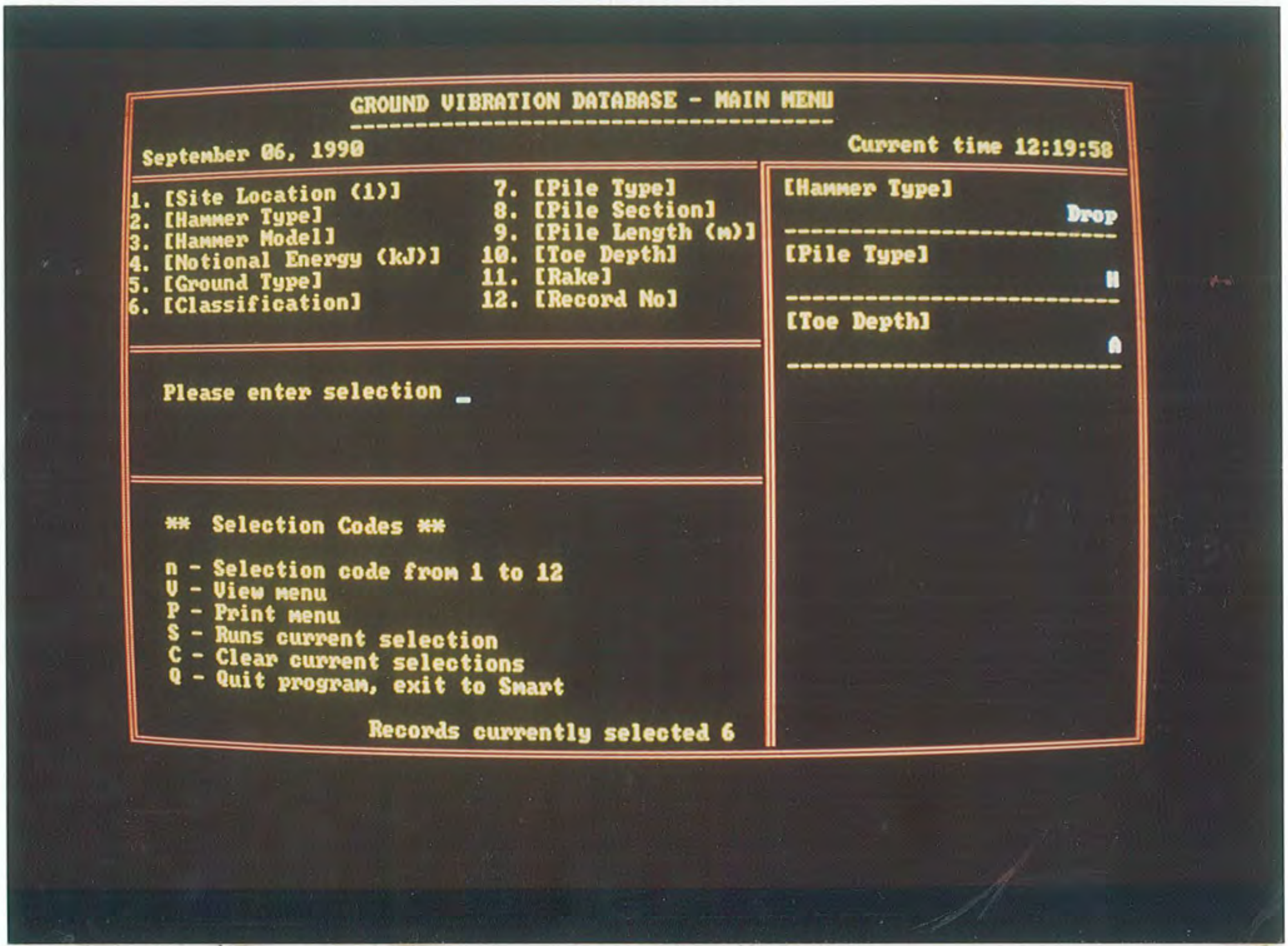
Toe Depth = A
Location = Blaydon, Contact 3

Dist (m)	Radial Vel. (mm/s)	Transverse Vel. (mm/s)	Vertical Vel. (mm/s)	Resultant Vel. (mm/s)
2	21.8	39.3	42.9	51.4
3	23.5	33.5	36.3	45.6
5	24.4	23.7	26.0	35.5
6	23.7	19.7	21.9	31.2
7	22.4	16.2	18.6	27.3
9	18.6	10.5	13.8	20.8
10	16.2	8.3	12.2	18.1
12	11.1	5.0	10.0	13.7
13	8.5	3.8	9.3	12.0
14	6.2	2.9	8.8	10.5
16	2.3	1.7	8.1	8.1
17	1.1	1.4	7.7	7.1
18	0.5	1.2	7.3	6.4
20	0.4	0.9	5.6	5.1
21	0.4	0.8	4.4	4.6

Any key to continue

Figure 3.9/10

DMM database program in use



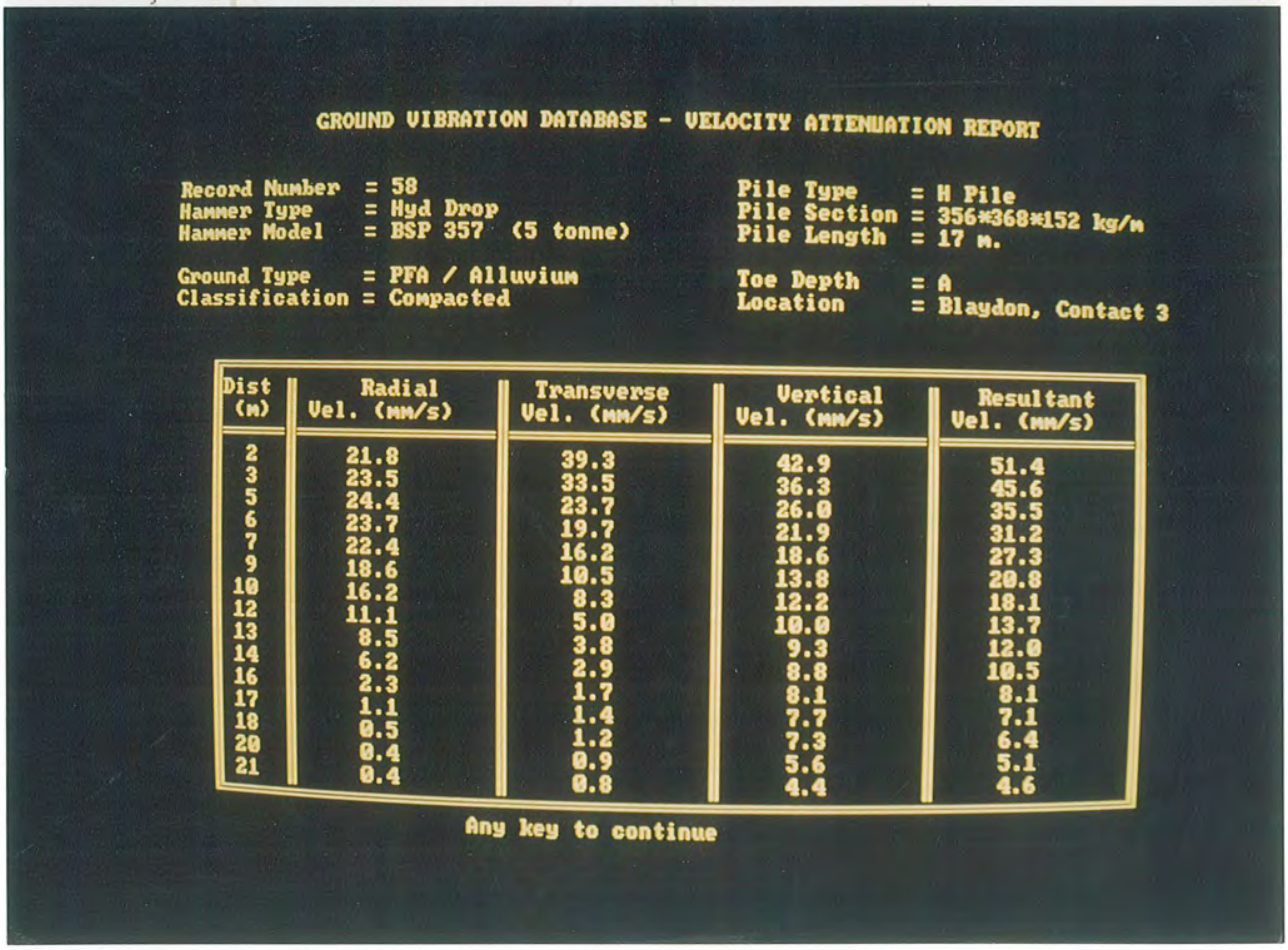
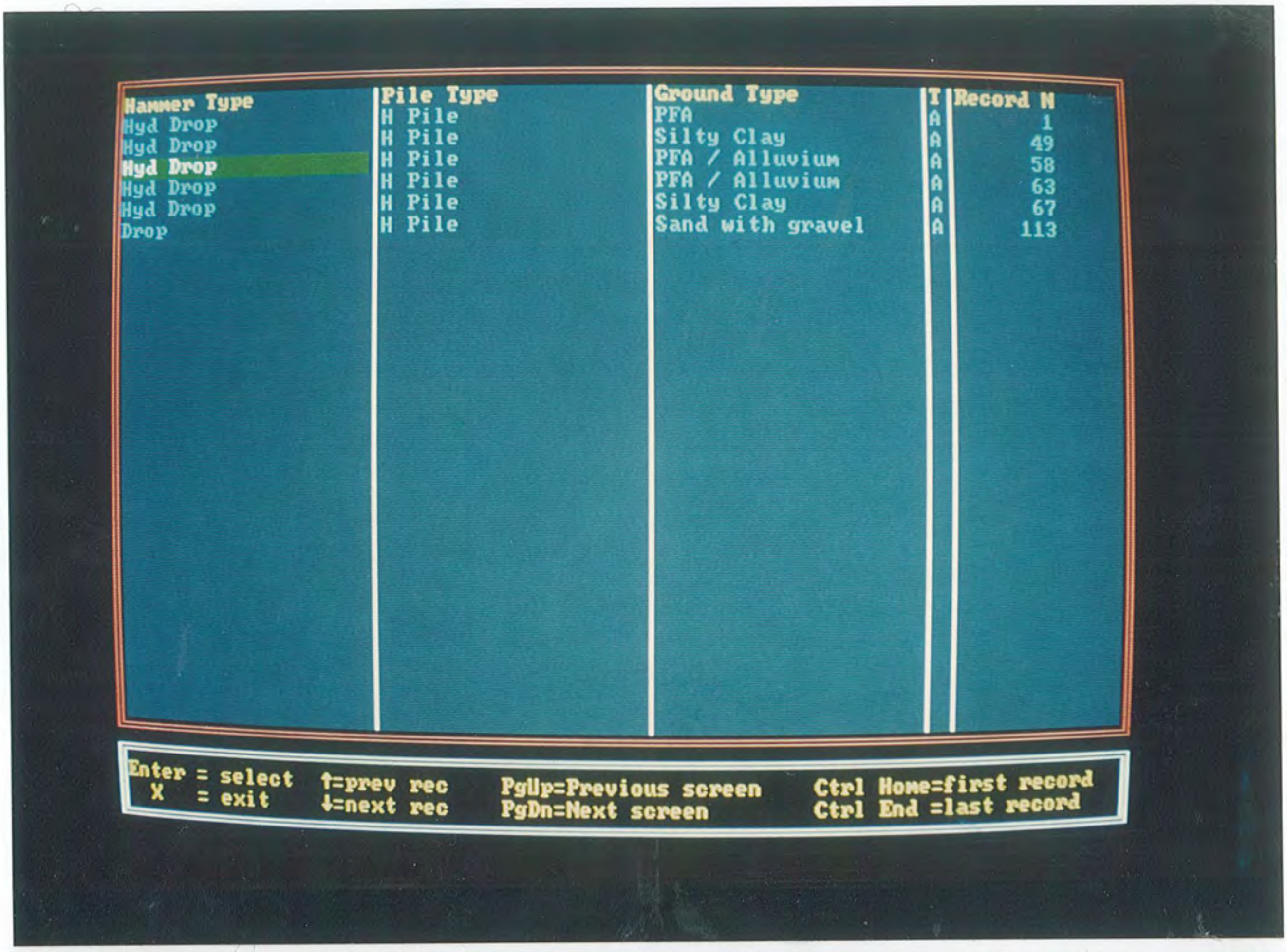


Figure 3.9/10

DMM database program in use



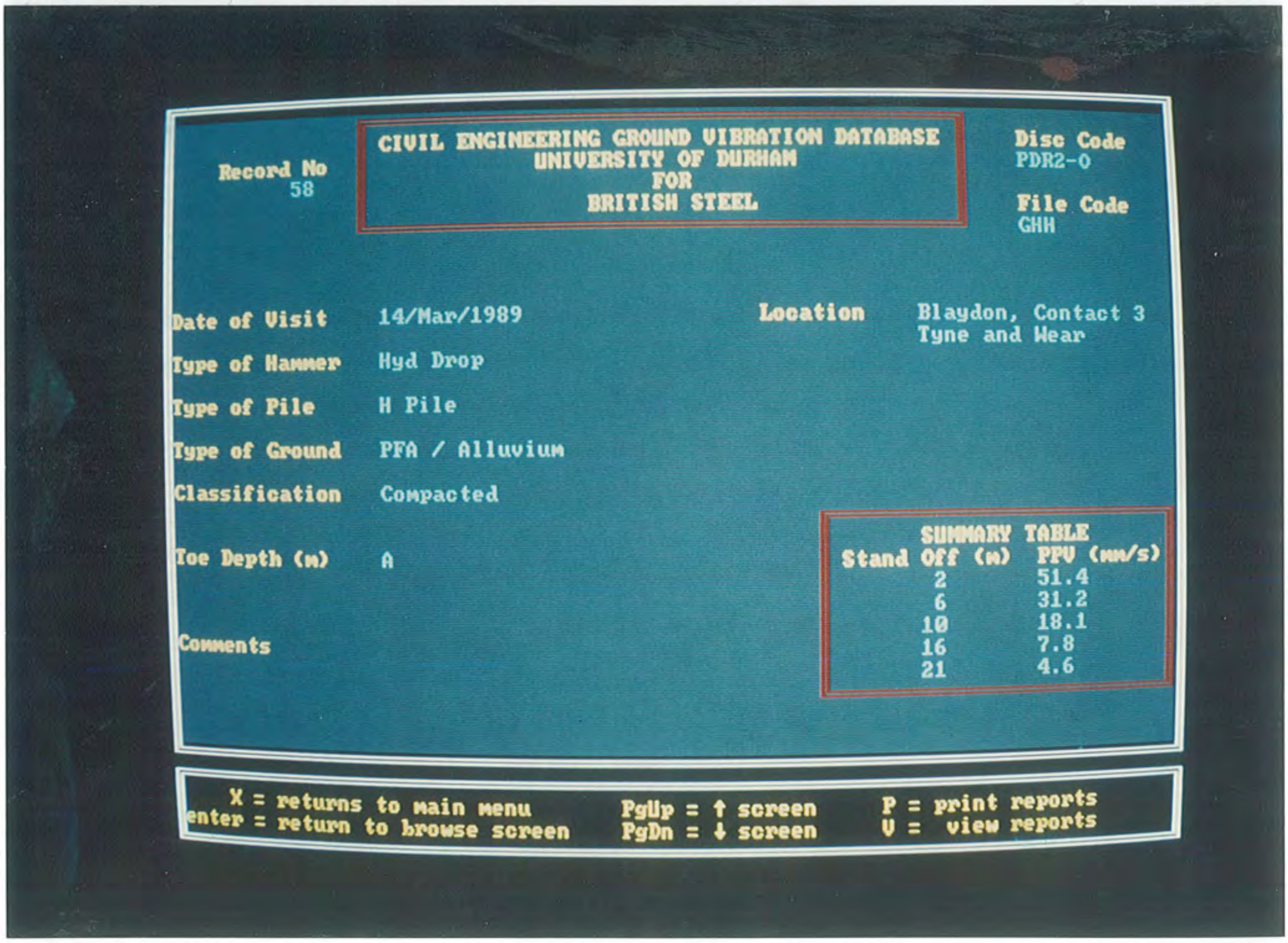


Figure 3.11/12

View screens from DMM database program

Examples of Polynomial Coefficients used in the Ground Vibration Database

	Velocity	Acceleration	Displacement
Radial			
A	-1.337	-5429.569	-0.841
B	8.736	2764.687	0.426
C	-1.008	-278.232	-0.041
D	0.080	7.906	0.001
Transverse			
A	-15.854	-2437.507	-0.226
B	8.454	1313.826	0.109
C	-0.829	-133.387	-0.010
D	0.024	3.865	0.000
Vertical			
A	43.017	3968.984	0.611
B	-7.828	-711.851	-0.087
C	0.586	47.636	0.005
D	-0.014	-1.068	0.000
Resultant			
A	15.946	-3450.569	-0.965
B	5.613	2226.145	0.310
C	-0.801	-232.021	-0.031
D	0.025	6.670	0.001

Equation of the form $A+B*x+C*x^2+D*x^3$

Table 3.1

4 Expert System

4.1 Introduction

The production of an expert system was the next progression of the ground vibration project. The database can only supply predictive results if the user carries out an essentially subjective iterative process on selected data. The expert system provides predictive estimations of expected levels of vibration by responding to user-supplied variables through rule-based procedures. These rules include calculations of the energy required to drive the pile, application of any suitable modification factors to this energy requirement, and selection of hammers. A structured set of algorithms are then applied, these algorithms being based on data from the Ground Vibration Database. The resulting predicted levels of vibration are then displayed; these levels can be referenced against user settable values or from National codes. The expert system represents the final stage of the Ground Vibration project.

4.2 Advantages over the Ground Vibration Database

The main aim of this stage of the project was to produce a tool that could be used for supplying a predictive estimate of vibration levels for a given piling system of hammer, ground and pile type. The database is primarily an historical filing system, that is every record represents one group of historical activities that are essentially unique. However, interfacing with this database through a menu driven query system, the database takes on a wider aspect incorporating selective data retrieval, enhanced by the interpolation of velocity readings between the five actually taken.

The database can only respond positively, however, if there are records present within the database which match the query criteria. A general query will produce numerous suitable records from the database. The user must then manually search through these records, either by tightening the selection parameters or by printing out hardcopies of the relevant reports. This process is both time and labour consuming; the expert system carries out this process automatically. Also, the database can be queried only on the physical characteristics of the event recorded. Selection cannot be made with respect to levels of vibration observed or restrictions placed thereon. The expert system can allow referencing to results.

The expert system incorporates additional sets of data previously unavailable to the user. The system can give an indication of the energy required to drive a pile under stated conditions. Hammers capable of delivering this magnitude of energy can also be selected from a large hammer database. The suitability of a hammer which the contractor wishes to use can be assessed, by incorperation of a hammer rating index (see 4.6). The expert system then uses sets of equations to estimate vibration levels, based upon the user-supplied information of pile and soil types, and upon deduced hammers/energies.

4.3 Software Choice

There are several expert shell packages available which could have helped in the production of this system. These shell systems offer the ability to link in various databases and datafiles, whilst maintaining a "natural language" interface through the shell.

Also several structured languages have expert system application packages available, which allow the body of the system to be written in Pascal for example, and the logical rule base resides as a separate package. This "bolt on" system also lets the systems designer use all the other packages available for the language for example, graphical routines, regression analysis and screen handling routines.

Finally, SmartWareII - an integrated applications package including seperate database, spreadsheet and text handling modules - was chosen for the whole system. The main factors in this choice were :-

* The software existed at Durham University and British Steel, Scunthorpe.

* Standardisation between the database and the expert system. The final Ground Vibration Project System allows the user to access the database and the expert system on the same software on the same personal computer.

* The expertise was available to write the system in SmartWareII.

* SPL, SmartWareII Programming Language, is a powerful 4GL clone language which was easily capable of handling all aspects of the expert system.

4.4 Expert Shell Engine

The system utilizes an approach which can be represented graphically by Figure 4.1. The system gains inputs from the user via an opening user interface, a simple set of question and answer routines. After this the system will have all the data it requires to calculate the final vibration levels. This data is then applied to particular algorithms to calculate the energy required to drive the pile for the four hammer types - namely Drop, Diesel, Air and Vibrodriver. Once these energies are known, hammer models can be selected that are most suitable for supplying this energy. The hammers are selected from a hammer database, "hammers.db" which is capable of updating by addition of new hammer models and types. The associated vibration levels may then be calculated, using the appropriate equations held in a sub-group datafile.

The engines of the system are the algorithms that calculate the energy required to drive the pile. The four main hammer groups are calculated in three distinct stages, Drop and Diesel as one group, Air and Vibrodriver separately. However the heart of the system is the sub-grouping which gives the system its flexibility and is discussed in detail below.

4.4.1 Sub Group Divisions

After consideration of data recorded and processed out of the database, it was recognised that separate equations were required to predict vibrations, dependent upon a consideration of hammer, pile and soil types. For example, vibrations from a vibrodriver on sheet piles attenuate more rapidly than those caused by a drop hammer on bearing piles. The sub groups that were used to represent the data in the expert system were chosen for their inherent simplicity. The more complex the sub divisions, the greater the accuracy of the predicted result. In addition, the finite amount of data collected, and its uneven spread implied that the greater the number of sub divisions, the smaller the sample size of each grouping. A compromise was reached with the following sub divisions which provided a good coverage of the data with a representative sample size. The subdivisions chosen were based on the following :-

Hammer Type	**Pile Type**	**Ground Type**	**4.1**
Air			
Drop	Sheet	Granular	
Diesel	Bearing	Cohesive	
Vibro			

The sixteen groups that could be represented by the above system were all manually graphed and logarithmic regression analyses carried out. A manual approach was adopted because some of the datasets used were non-typical and yet still valid. A manual approach allowed complex weighting processes that could accommodate these events.

The regression analyses produced the constants which were used in equation 4.2. Figure 4.2 shows how the constants were calculated and Table 4.2 tabulates the values used in the expert system.

4.5.2 Logarithmic Sub Group Equations

The work carried out by Attewell and Farmer (1973) in producing logarithmic equations to describe the levels of vibration due to pile driving has been mentioned previously. In the database project this method was not chosen (see Section 3.2.1) because the cubic fit was thought to provide a more precise and specific solution for any one particular case.

However, when the expert system was being designed based upon large groups of data, there were several aspects of this earlier work which required examination. Namely :

* Attewell and Farmer utilized an approach which took into account the nominal input energy of the hammer used.

* The Attewell and Farmer methodology had not been applied to the data collected for the database.

The general form of the logarithmic equation generated by Attewell and Farmer could be stated as :

$$V=k\ (W^{0.5}/R)^{x} \qquad 4.2$$

where

V = Resolved Velocity (mm/sec)

W = Nominal input energy (J.)

R = horizontal surface distance (m)

k , x = constants

If k and x could be derived for each of the proposed sub-groups (see section 4.5.1) then this system of equations could be used to predict vibration levels for a given hammer, pile and soil combination. Once the hammer was selected, its nominal energy rating could be supplied into the equation.

This would make the basic operation of the system comparatively simple as one of the most important factors, namely nominal energy input, could be regarded as an independent variable. It is important always to be consistent with the use of nominal hammer energies; nominal implies use without considering the efficiency of the hammer blow. The amount of hammer energy actually transmitted to the pile is less than the loss of hammer potential energy, and the energy transmitted into the soil smaller again. Efficiency differences between hammer types are taken into consideration, as further detailed in Section 4.5.

Moreover, these important equations had never been applied to the data recently collected. In producing the sub-groups (see section 4.5.1) actual graphs were produced, and on to which the original Attewell and Farmer lines could be superimposed. A sample of the results are shown in Figure 4.3 and prove that the work carried out 17 years previously was validated by modern data, except for the case of vibrodrivers.

The Attewell and Farmer equations proved to be the ideal equation system with which to drive the expert system. For this reason this approach, rather than the cubic, was chosen.

4.5.3 Elimination of Toe Depth

A chosen parameter of the database was the subdivision of the available site records into toe depth bands (see Section 3.3.3). When the expert system was under design, a study was carried out into the effect of toe depth on the maximum level of vibration. This study, by means of graphical analysis would seem to indicate that to consider the piling as one single operation could be sufficient to model any one part of that operation. In the cases where only the vibrations caused from the piling of the lower portions of the pile are known - toe depths C and D - enhancement is required. By selection of maximum values of records for both shallow and deep toe conditions, an expected maximum can be deduced for the whole drive. This means that, essentially, the toe depth of the pile can be neglected.

4.5.4 Drop and Diesel Hammer Selection

The algorithms constructed throughout the expert system engine are different for the two pile types, i.e. bearing and sheet piles are always treated differently. The main reason for this is that the British Steel Piling Handbook, from which much of the data emanates, treats the pile types separately.

In calculating the energy requirements for sheet piles, Table H1 on page H3 of the British Steel Piling Handbook gives an indication of the energy ranges required to drive sheet piles in pairs or as singles. These figures relate only to diesel hammers.

Much work has been carried out on the relative efficiencies of diesel and drop hammers (see Testing and Analysis Internal Report, 1982) and representative efficiencies were in the ratio of 80:60. The drop hammer energy requirements were thus deduced from the basis of the diesel hammer data. A simple system like this can be used as the operation of both hammers is very similar. Both are impact hammers, the only difference being the manner in which the impact is created. A reduction factor of 80% was applied to the required hammer energies quoted in the Table H1. This modifier takes into account the energy ranges quoted in the Table, of which the mean is used, and the safety factor assumed to be inherent within that table.

Basically the Table was converted into a database, the database being keyed on the pile section, the pile depth and the ground type. This database is known as "s_e.db". For ground type a modifier of 10% was applied, this modifier being explained in Figure 4.4. This database could be searched with the user-supplied data to produce the energy required to drive the piles for diesel and drop hammers.

Bearing piles were treated differently, the algorithm used being:-

$$E = m*l*k \tag{4.3}$$

where

E = Energy required to drive pile (kJ)

m = mass per unit length of pile (kg/m)

l = total length of pile (m)

k = modifying constant

The mass per unit length and depth of pile are user-input, and only the modifying constant needs to be system-calculated. If the pile is greater than 20 metres long, a 10% enhancement is used. This is required because, under testing, the algorithm did not supply enough energy for the longer piles. The energy required is also modified on ground condition, as previously explained in Figure 4.4.

This simple alogorithm has proved very effective in providing energy requirements and is discussed further in Chapter 5.

4.5.5 Air Hammer Selection

The operation of an air hammer, as described in Figure 1.3, could be described as a sharp chiselling action rather than a simple impact. Their use in industry is increasingly rare, since they produce high levels of noise in operation and their efficiency is far below that of the competitors. Ironically, they also produce much lower levels of vibration.

Although there are many manufacturers of air hammers, those in most common use in this country are produced by BSP (British Standard Piling). The database has only one occurrence of an air hammer not manufactured by BSP.

To calculate the air hammer to be used to drive a specific pile, the Table H2 on page H4 of the British Steel Piling Handbook is used. This quotes directly the BSP model to be used for that purpose. This table is designed into the previously mentioned database "s_e.db". However, instead of holding energy levels, it holds an actual hammer models.

For selection of an air hammer rating for bearing piles, Tables H1 and Tables H2 are effectively overlaid to produce a comparison of diesel hammers against air hammers. This comparison is then used to chose a specific air hammer based upon the selection of the other impact hammers.

4.5.6 Vibrodriver selection

Vibrodrivers operate on a principle which involves no impact (see Uromeihy 1990), and so the techniques employed previously must be altered. Great efforts were made to utilize a system that whilst different from impact calculation, could actually be incorporated into the same system.

Several manufactures of vibrodrivers suggest methods for selecting the size of hammer to be used for a specific project. Naturally, these different methods produce different results. The most consistent was that of ICE (International Construction Equipment) and it is that method that is employed.

The method relies upon the centrifugal force generated by the vibrodriver, as the equivalent parameter to nominal energy input for an impact hammer. The method is described below :-

$$C = f * l \qquad 4.4$$

where

C = Centrifugal force (kN)

f = Force required per linear metre (kN)

l = Total length of pile (m)

Throughout the "hammers.db" database, the centrifugal force field is carried, only being used in the case of vibrodrivers. This allows the same methodology to be applied throughout the hammer selection system. This simple method also has the advantage of being suitable for all pile types. In the case of bearing piles, the total length of pile is used in place of the linear metre.

4.5.7 Soil types and conditions

As stated in Table 4.1, the two soil types included in the expert system are granular and cohesive. This approach allows the user to differentiate between the dominant soil types; this is important because the soil type and condition have a marked effect on vibration attenuation.

The ground condition is split into three catagories for each of the soil types; loose, medium and dense for granular and soft, firm and stiff for cohesive. These conditions have an important role in the calculation of energy required to drive the pile, as explained in Figure 4.4.

In the production of the sub-groups, it should be noted that fill was classed as a loose granular soil and Pulverised Fuel Ash (PFA) as a dense granular fill. Silty clays were grouped depending on the particular site in question - the proportion of silt in the clay will dictate its class.

If the user is in doubt which soil classification a particular ground lies in, various types may be chosen and a consensus of vibration levels achieved.

4.6 System output

On completion of the user-input information the system selects the suitable hammers to drive the pile and then displays an output screen (see Figure 4.5). The upper portion of the screen contains the user-input data as a summary, the lower portion containing the vibration levels. The screen may be hard copied by the use of the Print Screen key on most IBM standard keyboards.

Four columns are displayed, one for each of the primary hammer groups, the vibration levels being displayed as integer values. At the foot of each column is the hammer model that has been selected by the system to drive the particular pile.

Below the hammer model is a hammer rating, expressed as a decimal number. This hammer rating can be expressed as :

$$\text{Rating} = \frac{\text{Nominal energy rating of selected hammer}}{\text{Calculated energy required to drive pile}} \qquad 4.5$$

The closer this rating approaches unity, the more suitable is the hammer for the project required. This hammer rating is very useful when used in conjunction with the preferred hammer routine (see Section 4.7).

The bottom line of the screen displays any velocity restrictions placed on the piling. The user may impose certain restrictions on the piling whilst inputting the original data. This is useful if an outside body, such as a local authority, has imposed certain limitations. These limitations form the basis for the output screen on which a colour coding overlays the vibration levels. A deep red signifies that piling levels are expected to be greater than the restrictions placed thereupon, while a light blue signifies that levels are expected to be acceptable.

The user may then change any one of the initially entered parameters and re-run the system to monitor the effect. This adds a great deal of flexibility to the system and allows the user to investigate fully the potential of a given construction project.

4.7 Preferred Hammer selection

This routine allows the user to force the system to choose a specific hammer. This is useful when a contractor would prefer to use a hammer in his or her possession, but is unsure of the effect on ground vibration levels. The user is able to pick any hammer from the hammer database "hammers.db". However due to practical limitations only one preferred hammer may be selected at one time.

The hammer rating will give the user an idea of how suitable the chosen model is to drive the pile in question.

4.8 User Interface and error trapping

Although the expert system was designed to be used by personnel who understood piling, for example employees of British Steel, they are not computer specialists. The decision was taken early in the project to ensure that the system was resilient and available for use by any level of computer user.

The method by which the user interfaces with the system is via question and answer routines. The responses required from the user are all one word or numerical answers - there is no natural language interface. By simplifying this interaction, error trapping becomes much more of a simple task. Each question has a finite number of correct replies and these replies are stored within the system. Automated routines can then prompt the user if either the reply given is incorrect, or indeed if the user simply requires assistance.

Where appropriate, the initial letter of the response will be sufficient to choose that item. If the question requires a simple "yes" or "no" response, the initial letters will only be accepted. The ability to "MASK" i.e. only accept those listed responses, is a powerful command of SmartWareII. The system issues a beep if the reply is incorrect and prompts the user to try again.

When a simple response is required, the system will frame the question in such a manner as to suggest the responses :

For Example

Are the piles being driven in (P)airs or (S)ingles ?

In this particular question, only the responses contained in the brackets, case insensitive, will be accepted.

The facility to rerun the system whilst changing selected parameters is driven via a set of menus. These menus allow the system to be operated in an unstructured manner. However this flexibility multiplies the potential for error. The system relies upon the manipulation of user input variables to produce its results. To then go back and change one or more of the variables requires care. System-set flags are comprehensively used so that the system has a complex internal logic of its own.

4.9 Sources of Information

By definition, the expert system contains the summation of available knowledge in the Ground Vibration Team at Durham University. The experience gained while conducting field work, particularly from piling crews, proved particularly useful. The British Steel Piling handbook was used in compiling the algorithms for nominal energy required and the staff of the Piling Technical Services department were helpful throughout.

A special mention should be given to Steffens - Structural vibration and damage (1985), a constant source of information and ideas.

Various piling hammer manufactures were approached throughout the project. Assistance was never denied and their interest and enthusiasm was encouraging.

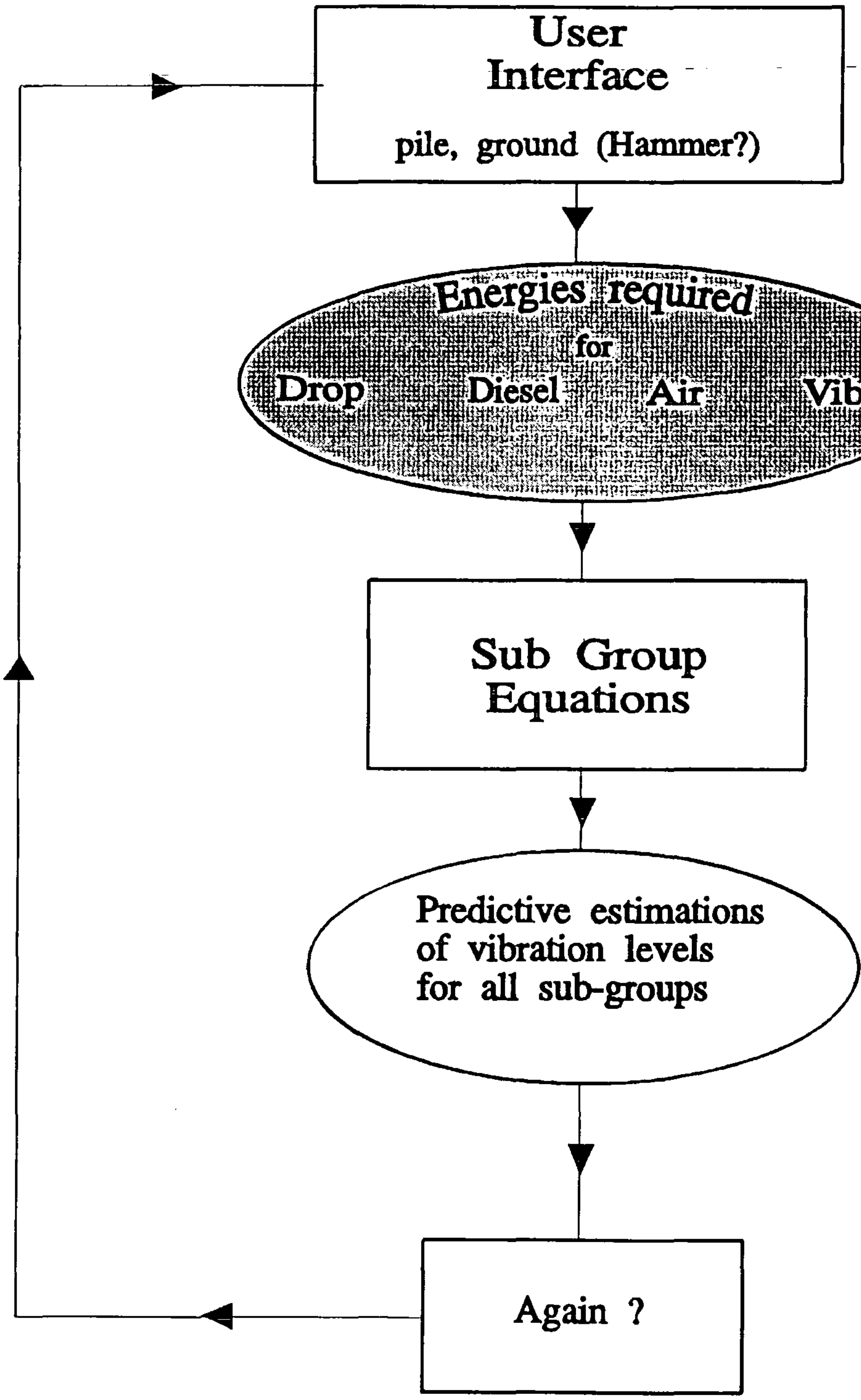
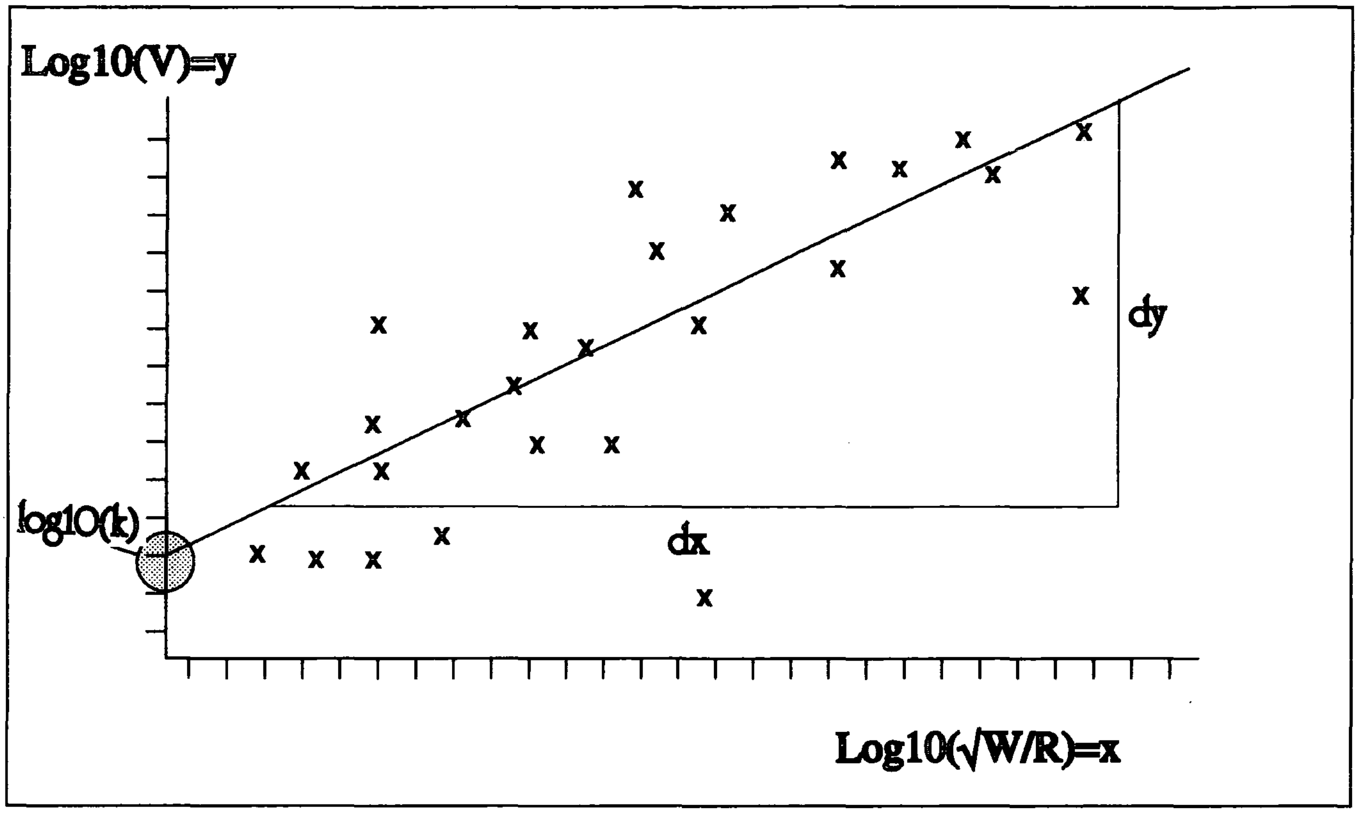


Figure 4.1

Schematic representation of flow of data through expert system



Equation of the form:-

$$\mathrm{Log10}(V) = \log 10(k) + m * \mathrm{Log10}(\sqrt{W}/R)$$

where :-

m = gradient of regression line i.e. $\frac{dy}{dx}$

k = intercept on y axis

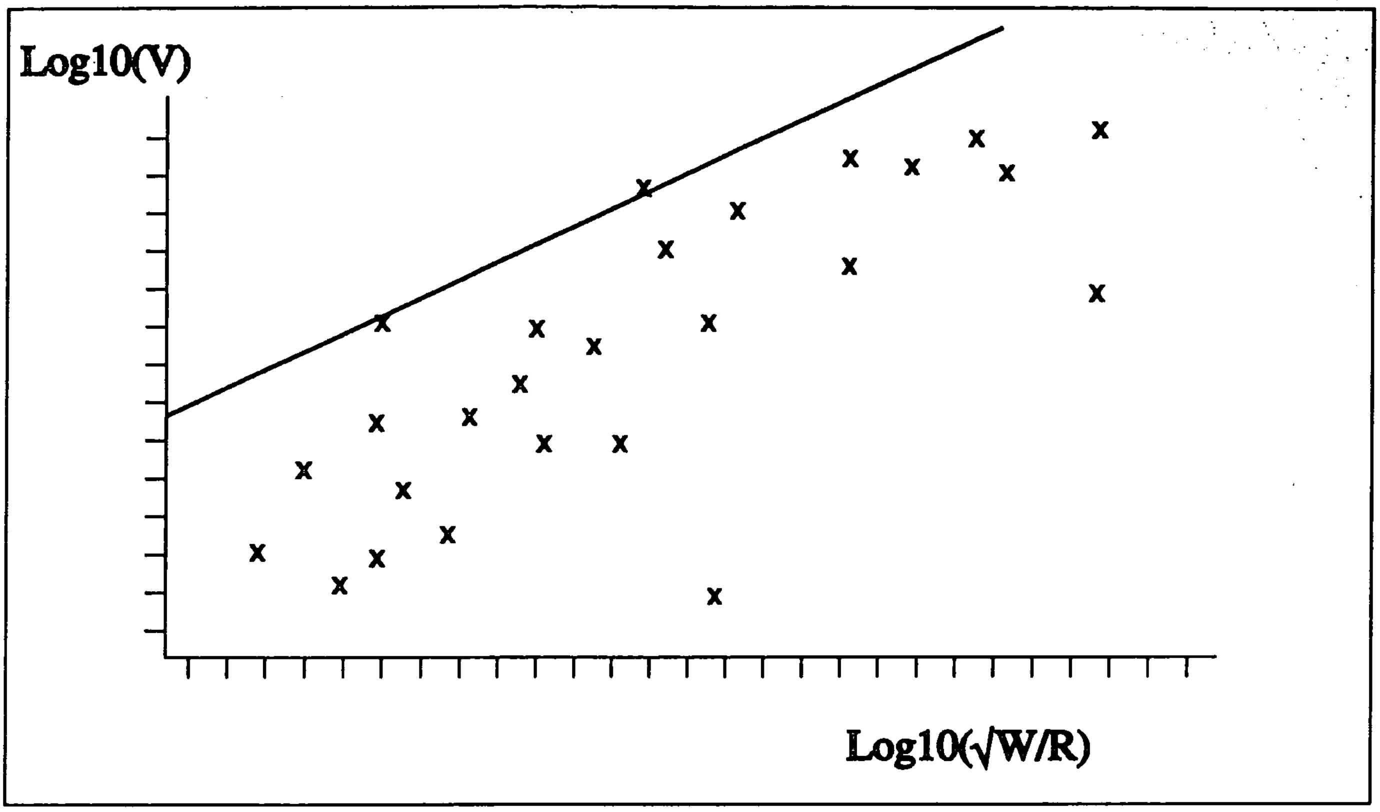
V = Peak Particle Velocity (mm.sec)

W = Nominal Hammer Energy (kJ)

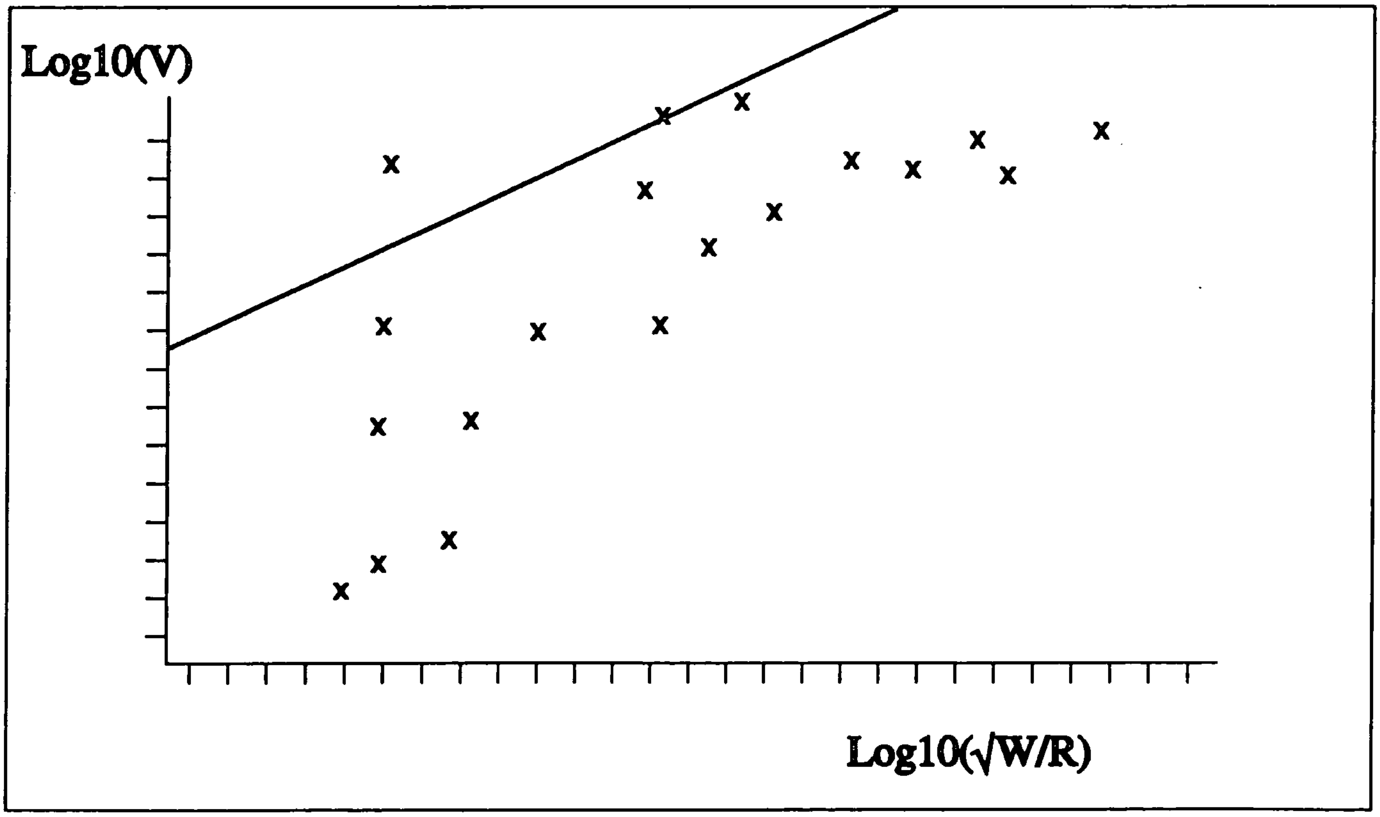
R = Radial Stand Off (m)

Figure 4.2
Logarithmic Regression Analysis for Expert System

Attewell and Farmer equations compared with the Expert System data



Data shown - drop hammers in granular soils



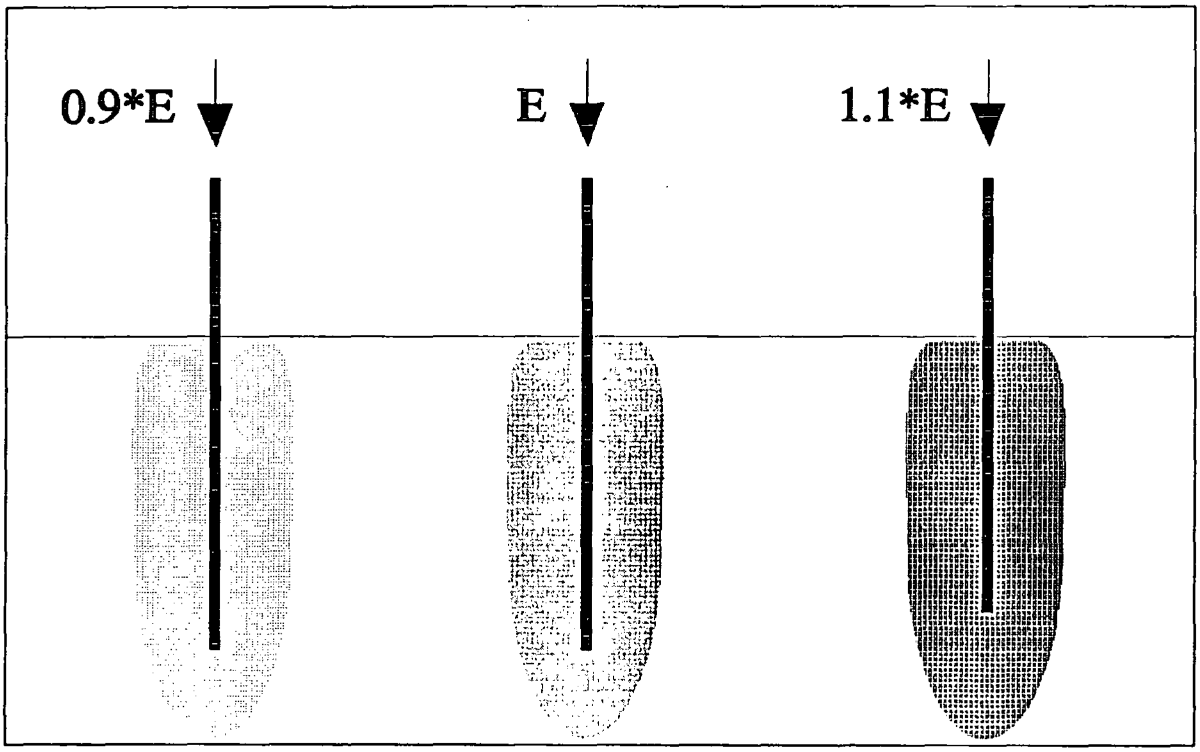
Data shown - diesel hammers in granular soils

——— Attewell and Farmer upper bound equations

Figure 4.3

E = Energy required to drive pile

Energy modification required to overcome increased localised friction due to greater ground stiffness.



Condition: Loose or Soft

$E = 0.9 * E$

Condition: Dense or Stiff

$E = 1.1 * E$

Figure 4.4

Schematic representation of ground condition modifier

Table showing the sub-groups and values used in the Expert System

Group No.	Hammer Type	Ground Type	Pile Type	m	k
1	Drop	Granular	Sheet	0.92	12.9
2	Drop	Granular	Bearing	0.54	12.0
3	Drop	Cohesive	Sheet	1.33	11.8
4	Drop	Cohesive	Bearing	0.79	19.1
5	Air	Granular	Sheet	0.92	15.8
6	Air	Granular	Bearing	0.39	11.1
7	Air	Cohesive	Sheet	0.60	10.0
9	Diesel	Granular	Sheet	0.75	17.0
10	Diesel	Granular	Bearing	1.00	11.5
11	Diesel	Cohesive	Sheet	1.33	15.9
12	Diesel	Cohesive	Bearing	0.91	11.0
13	Vibrodriver	Granular	Sheet	1.00	25.9
14	Vibrodriver	Granular	Bearing	0.60	25.1
15	Vibrodriver	Cohesive	Sheet	1.07	31.6
16	Vibrodriver	Cohesive	Bearing	0.85	25.9

Table 4.2

5 Comparison between database and expert system

5.1 Introduction

In order to test the accuracy of the element of the expert system which gives predictive estimations of vibration, random records were chosen from the database and run through the system. By choosing records from the fifteen sub groups, the individual logarithmic algorithms could also be assessed within the framework of the predictive system. The hammer selection element of the expert system was less easy to test, but rating indices indicated the suitability of the hammer used in a number of cases.

5.2 Method of Comparison

To ensure a good coverage over all the piling system combinations, the database was split up into its different hammer types. Each record is then assigned to a particular sub group, according to its dominant ground and pile type. Records were chosen randomly from this Table, one from each of the main groups (apart from group 7 which is unrepresentative due to its small sample size).

The operational details of each record were noted and these details were then used to represent that record to the expert system, namely pile type, hammer model and ground type/condition with a range of piling depths.

It was the depth of piling that added the only degree of uncertainty into the comparative proceedings. The database grouped together several records to be representative of a toe depth banding during piling. This grouping produces the maximum levels of vibration recorded for a specific series of piling events. In querying the expert system with the parameters for one of the records within that grouping, the comparison was being made against the maximum values of the elements of that group.

5.3 Results of Comparison

The results of the fifteen comparisons are shown in Table 5.1 and a statistical analysis of the results is shown in Table 5.2. A summary follows.

Two of the comparisons produced results from the expert system that were significantly lower than those recorded on the database. In one of these cases, record 110, sub group 14, recorded vibration levels were significantly higher than predicted values between the 5m to 20m stand off distances. This can be partly explained because the record in question was recorded in loose sand which normally results in rapid signal attenuation (Uromeihy, 1990).

Of the remaining comparisons, eleven produced results within a margin of 30% positive or 5% negative i.e. the expert system predicted levels of vibration that were within 30% greater or 5% less than those stored on the database. The remaining two comparisons produced predicted results that were significantly higher than those stored on the database. However, these two results were exaggerated by large over-statement at stand offs between 10 and 20 metres, statistically difficult to account for. Considering the amount of data handling and manipulation involved in the storing of the data in the system, these results represent an acceptable margin of overstatement.

All the records were chosen at random and the results are a vindication of the methods used in the analysis and data handling. Measured vibrations in variable ground caused by high energy, yet mechanically crude pile-hammer combination, will inevitably show large variations, and the occasional "rogue" result. There is therefore a balance to be set for a predictive estimation algorithm, such that estimates will exceed previous measurements by an acceptably small margin in the large majority of cases. It is felt that the 15 equations, derived in Figure 4.2, achieve this balance.

The hammer rating indices on the fifteen examples chosen showed suitable, if not in some cases obscure, selections. The little used hammers that were selected in some cases merely act as an indication to the size of the hammer database. Data are not available as to the minimum hammer ratings which would define the lowest energy level for adequate driving. However the relatively large over-rating values suggested that in many cases hammer sizes could be reduced substantially if ground vibrations were a limiting factor. It may be that this is one of the major benefits offered by the expert system.

The differences in output information format are essentially a reflection of the different objectives persued in the development of the database and of the expert system. The database was seen as a filing system offering selective recall and required hard copy listing of selective records. The expert system was designed to offer rapid estimations of vibrations for comparative piling systems, and output was centred on a final screen of colour coded information allowing the making of a direct judgement or decision. This objective was achieved, but on occasion, a record of the information may be desired. This is achieved by a simple screen dump. In the running of the 15 random examples the benefits of the expert system were demonstrated strongly. The database and the expert system, based on the SmartWareII package, were developed and installed on a 20 Megabyte Research Machines Nimbus AX PC. The data for both systems can be transferred onto a single 3.5" diskette for easy transportation to other PC systems.

Table 5.1 - Database / Expert system Comparison Results

Group One (Diesel hammer / Granular Soil / Sheet Piles)

Database Record Number 26
Larssen 6, Medium Fill going to Firm Brown Clay, toe depth A
Hammer used - Kobe 25

Stand Off (m)	Recorded Database PPV (mm/sec)	Expert System PPV (mm/sec)
2	29.1	42.0
5	10.2	18.2
10	6.5	11.5
15	9.0	8.9
20	3.0	6.1

Group Two (Diesel hammer / Granular soil / Bearing plies)

Database Record Number 84
356*368*152, sand / Glacial clay, toe depth D
Hammer used - BSP DE50C

Stand Off (m)	Recorded Database PPV (mm/sec)	Expert System PPV (mm/sec)
2	17.4	25.0
5	6.2	13.0
10	6.4	10.5
15	8.5	8.5
20	3.4	4.2

Group Three (Diesel hammer / Cohesive soils / Sheet piles)

Database Record Number 15
Larssen 6, Firm Brown Clay, toe depth C
Hammer used - Kobe 25

Stand Off (m)	Recorded Database PPV (mm/sec)	Expert System PPV (mm/sec)
2		85.1
5	19.1	25.3
10	11.9	12.9
15	5.4	9.4
20	0	7.5

Group Four (Diesel hammer / Cohesive soils / Bearing piles)

Database Record Number 74
305*305*79, Silty Clay, toe depth B
Hammer used - BSP B15

Stand Off (m)	Recorded Database PPV (mm/sec)	Expert System PPV (mm/sec)
2	43.4	46.0
5	39.0	28.7
10	24.3	22.1
15	9.9	9.4
20	6.4	7.5

Group Five (Air hammer / Granular soils / Sheet piles)

Database Record Number 47
Larssen 16W, Sand, toe depth A
Hammer used - BSP 600N

Stand Off (m)	Recorded Database PPV (mm/sec)	Expert System PPV (mm/sec)
2	18.0	16.0
5	9.7	8.9
10	4.4	3.9
15	2.5	2.8
20	2.3	1.9

Group Six (Air hammer / Granular soils / Bearing piles)

Database Record Number 76
356*368*152, Dense sand going to Firm Clay, toe depth C
Hammer used - BSP 900N

Stand Off (m)	Recorded Database PPV (mm/sec)	Expert System PPV (mm/sec)
2	12.6	14.9
5	7.1	10.3
10	6.9	8.6
15	8.5	7.4
20	6.4	6.5

Group Seven (Air hammer / Cohesive soils / Sheet piles)

Database Record Number 102
Larssen 16W, Soft Silty Clay, toe depth A
Hammer used - BSP 700N

Stand Off (m)	Recorded Database PPV (mm/sec)	Expert System PPV (mm/sec)
2	14.7	11.5
5	4.8	6.0
10	1.9	4.4
15	2.6	3.3
20	1.0	2.9

Group Nine (Drop hammer / Granular soils / Sheet piles)

Database Record Number 32
Larssen 16W, Dense sand with some clay, toe depth A
Hammer used - BSP 357, 3 tonne weight, 1.2m drop height

Stand Off (m)	Recorded Database PPV (mm/sec)	Expert System PPV (mm/sec)
2	35.2	41.2
5	18.2	16.2
10	7.2	9.6
15	2.0	7.9
20	2.0	7.3

Group Ten (Drop hammer / Granular soils / Bearing piles)

Database Record Number 59
356*368*152, Medium compacted PFA with alluvium, toe depth B
Hammer used - BSP 357, 5 tonne weight, 1m drop height

Stand Off (m)	Recorded Database PPV (mm/sec)	Expert System PPV (mm/sec)
2	22.2	44.1
5	15.3	14.7
10	10.1	8.8
15	4.8	5.5
20	2.8	4.4

Group Eleven (Drop hammer / Cohesive soils / Sheet piles)

Database Record Number 38
Larssen 25W, Firm London Clay, toe depth B
Hammer used - BSP 357, 7 tonne weight, 1.2m drop height

Stand Off (m)	Recorded Database PPV (mm/sec)	Expert System PPV (mm/sec)
2	83.1	118.9
5	31.9	27.6
10	7.2	14.0
15	0	7.5
20	0	5.6

Group Twelve (Drop hammer / Cohesive soils / Bearing piles)

Database Record Number 50
305*305*110, Firm Silty Clay, toe depth B
Hammer used - Banut 4 tonne winch drop

Stand Off (m)	Recorded Database PPV (mm/sec)	Expert System PPV (mm/sec)
2	28.3	31.4
5	15.3	11.9
10	7.5	7.2
15	3.9	5.3
20	3.6	4.2

Group Thirteen (Vibrodriver / Granular soils / Sheet piles)

Database Record Number 11
Frodingham 2N, Soft Chalk, toe depth B
Hammer used - ICE 416

Stand Off (m)	Recorded Database PPV (mm/sec)	Expert System PPV (mm/sec)
2	20.1	31.7
5		
10	5.0	7.9
15	1.7	4.5
20	3.5	3.2

Group Fourteen (Vibrodriver / Granular soils / Bearing piles)

Database Record Number 110
305*305*88, Loose sand with gravel, toe depth A
Hammer used - PTC 13HF1

Stand Off (m)	Recorded Database PPV (mm/sec)	Expert System PPV (mm/sec)
2	24.0	23.9
5	18.6	12.4
10	17.6	10.4
15	17.1	8.2
20	10.1	6.4

Group Fifteen (Vibrodriver / Cohesive soils / Sheet piles)

Database Record Number 25
Larssen 16W, Firm London Clay with gravel layers, toe depth A
Hammer used - Kobe 25

Stand Off (m)	Recorded Database PPV (mm/sec)	Expert System PPV (mm/sec)
2	25.6	29.0
5	8.1	8.6
10	4.8	4.3
15	6.1	2.8
20	2.1	2.5

Group Sixteen (Vibrodriver / Cohesive soils / Bearing piles)

Database Record Number 110
356*368*152, Soft Glacial Clay with sand layers, toe depth C
Hammer used - Kobe 25

Stand Off (m)	Recorded Database PPV (mm/sec)	Expert System PPV (mm/sec)
2	21.5	39.3
5	4.0	15.5
10	2.2	10.0
15	5.0	7.5
20	1.6	6.1

Statistical analysis of Database and Expert system Comparison

Group No.	Station A	Station B	Station C	Station D	Station E	Mean Error
1	+30%	+44%	+43%	-1%	+50%	+33%
2	+30%	+50%	+39%	0%	+20%	+25%
3	n/a	+25%	+7%	+42%	n/a	+25%
4	+6%	-26%	-9%	-5%	+15%	-4%
5	+11%	-8%	-11%	+12%	-17%	-3%
6	+15%	+30%	+19%	-7%	+1%	+11%
7	-21%	+20%	+50%	+21%	+65%	+26%
9	+14%	-10%	+25%	+75%	+73%	+35%
10	+49%	-4%	-12%	+12%	+36%	+16%
11	+30%	-13%	+48%	n/a	n/a	+22%
12	+10%	-22%	-4%	+26%	+14%	+5%
13	+37%	n/a	+37%	+60%	-8.5%	+31%
14	-1%	-33%	-40%	-52%	-36%	-25%
15	+12%	+6%	-10%	-48%	+16%	-5%
16	+45%	+75%	+88%	+33%	+73%	+63%
Mean	+20%	+9%	+18%	+13%	+21%	17%

Mean variance =17%

Table 5.2

6 Conclusions

6.1 Achievements

This project has continued the work carried out on the area of piling induced ground vibration by the Ground Vibrations Group at Durham University. The aim of this work was two-fold. Initially what was required was a database to store the results of ground vibrations monitoring. Secondly, an expert system was required to produce predictive estimates of ground vibration levels. Both of these aims have been achieved.

A database which now exists contains some 120 records of separate ground vibration events. Data are stored in the form of polynomial equations and model the behaviour of radial, transverse, vertical and resultant components of velocity, acceleration and displacement. This polynomial approach was pioneered for this project and leads to accurate fitting of site data. These equations can be accessed with the use of a menu driven query system. This query system is designed to be operated by operators of any skill level. By querying the system with the details of a site to be piled, an indication of the expected levels of vibration can be attained. Formal reports can be shown on the screen and hard copy produced if required.

Records from some 70 site visits were available from work by Uromeihy (1990), but a further 50 or so records were required so as to provide statistically viable groups of data for each of the hammer, pile and ground combinations. The majority of these visits were undertaken by the writer over an 18 month period, to piling sites throughout England and Scotland.

An expert system now exists to enable the user to obtain predictive estimations of ground vibration levels. This expert system is based on data from the ground vibration database sorted into sixteen sub groups, dependent upon pile type, hammer type and ground type. These sub groups in conjunction with associated hammer energies can produce predictive levels of vibration for a given piling system. The expert system employs several algorithms to calculate the amount of energy required to drive a particular pile. These algorithms have been developed purely for this project and represent a new approach to the predictive ground vibration problem. The system can also identify suitable hammers to drive, based on the associated energies. Vibration limitations expressed through industry accepted standards may also be applied. While the expert system offers a powerful tool to assist in advising on ground vibrations, its limitations, with respect to the inherent variability of ground vibrations, must be recognised.

6.2 Further Work

The ground vibration database has been constructed in such a way as to be easily enhanced. The more records that are in the database, the more likely that queries will produce efficient and cost-effective results. Pile driving is widespread throughout the United Kingdom and the problems caused by the driving of piles still exist. It is hoped that in the future the database will continue to grow and provide service to the construction industry.

The effects of ground borne vibration on structures have been investigated previously, notably by Uromeihy and Selby (1990) and Steffans (1985). Further studies in this area would lead to a greater understanding of the factors that affect ground vibration levels and also produce the wealth of data that is required for intensive research. Research proposals which allow a structure to be instrumented and subjected to various levels of piling-induced ground vibrations would be the best way to progress in this area.

Finally it is noted that more work is required in the area of low amplitude vibration and their effects on, for example, advanced manufacturing facilities. Limits that are being suggested by certain semi conductor manufacturers and statutory bodies are so low that both the science of isolation and the estimation of vibration level and frequency compostition will become more and more important as time goes by.

APPENDICES

APPENDIX 1

Site Visit Dairy

No.	Date	Site	Pile	Hammer	Persons	Disc	File	Comments
1	22.09.86	Whalley	Concrete	Drop	AU & AS	DATA1	WAL	Accrington road Whalley
						DATA2	FUG	Fugro test
2	25.09.86	Blaydon	H-pile	Diesel	AU & AS	DATA3	TYN	visit to Blaydon Area 1
3	26.09.86	Blaydon	H-pile	Diesel	AU & AS	DATA3	TYN	second part of pile
4	26.09.86	Blaydon	Sh-pile	Vibro	AU & AS	DATA3	BSV	Sewerage System
5	03.10.86	Spring Well	H-pile	Diesel	AU & AS	DATA3	SHD	Harbour & General
6	07.10.86	Newcastle	Sh-pile	Air	AU & BS	DATA4	NSA	Newcastle Dockyard
7	24.10.86	Blaydon	H-pile	Vibro	AU & BS	—	—	PDR1 failed
8	30.10.86	Blaydon	H-pile	Vibro	AU & AS	DATA5	BHV	only channels 1,2,3 recorded
9	03.11.86	Blaydon	Tube	Vibro	AU & AS	DATA8	HOW	Tube case driving
10	05.11.86	Blaydon			AU & AS			Failure in the hammer
11	06.11.86	Blaydon	H-pile	Vibro	AU & AS	DATA6	RAK	Area(2), Raking pile
12	11.11.86	Blaydon	H-pile	diesel	AU & BS	DATA4	FAR	second part of pile
13	14.11.86	Blaydon			AU & BS			failure in the generator
14	29.11.86	St.Annes	Sh-pile	Vibro	AU & BS	DATA10	POL	first part
15	02.12.86	St.Annes	Sh-pile	Hydr	AU & BS	DATA10	ANS	second part
16	04.12.86	Blaydon	H-pile	Vibro	AU & AS	DATA9	RIV	Area(3), S.Tyne River
17	05.12.86	Blaydon	H-pile	Diesel	AU & SR	DATA11	DIS	Second part
18	29.02.87	Keighley	H-pile	Hydr	AU & AS	—	—	introductionary visit
19	02.03.87	Keighley	H-pile	Hydr	AU & AS	DATA12	KGL	pile number 1
			H-pile	Hydr	AU & AS	DATA13	ELY	pile number 7
20	10.03.87	Keighley	H-pile	Hydr	AU & BS	—	—	PDR1 failed
21	13.03.87	Keighley	H-pile	Vibro	AU & BS	—	—	PDR1 failed
22	23.03.87	Keighley	—	—	AU & BS			no driving
23	02.04.87	Keighely	H-pile	Hydr	AU & BS	DATA14	KRW	River Worth
24	14.04.87	Grimsby	Sh.pile	Air	AU & BS	DATA15	GSA	the pile just set up
25	15.04.87	Grimsby	Sh.pile	Air	AU & BS	DATA16	GSA	first part driving
			Sh-pile	Diesel		DATA17	GSD	second part
26	28.04.87	Keighley	Sh-pile	Vibro	AU & BS	DATA18	KVS	Close to the houses
			h-pile	Hydr		DATA19	KHH	River Worth
27	14.05.87	Workington	Sh-pile	Vibro	AU & BS			no driving
28	18.05.87	Keighley	H-pile	Vibro	AU & BS	DATA20	KVH	River Aire
29	21.05.87	Keighley	H-pile	Diesel	AU & AS	DATA21	KDH	River Aire

Site Visit Dairy

No.	Date	Site	Pile	Hammer	Persons	Disc	File	Comments
30	27.05.87	Workington	Sh-pile	Vibro	AU & SL	—	—	crack in river bank wall
31	18.06.87	Grimsby	Sh-pile	Diesel	AU & AS	DATA22 DATA23	GSD GDS	data recorded by PDR1 data recorded by PDR2
32	30.06.87	Workington	Sh-pile	Vibro	AU & AS	—	—	no pile driving
33	03.07.87	Workington	Sh-pile	Vibro	AU & JO			failure in river bank
34	12.08.87	St.Helens	Sh-pile	Vibro	AU & BS	DATA24	SSV	pile extraction
35	14.08.87	Newbiggin	Sh-pile	Vibro	AU & AS	DATA25	NSV	sea defence wall
36	26.08.87	Newbiggin	Sh-pile	Vibro	AU & BS			no pile driving
37	03.09.87	Selby	Concrete	Drop	AU & AS	DATA26 DATA27	SCD MCD	1st pile 2nd pile
38	04.09.87	St.Helens	Sh-pile	Air	AU & BS	DATA28	SSA	cofferdam construction
39	15.09.87	Newbiggin			AU & MA			no pile driving
40	05.10.87	Edinburugh	Sh-pile	Vibro	AU & JO			Failure in the hammer
41	02.12.87	Edinburgh	Sh-pile	Hydr	AU & BS	DATA29	ESH	recording achieved
42	10.12.87	Swillington	Sh-pile	Vibro	AU & BS	DATA30	SSV	retaining whall
43	28.01.88	Immingham	Tube	Drop	AU & JO	DATA31 PDR-A	ITH IDP	Pier 7, dockyard PDR2 records
44	03.02.88	Immingham	Tube	Drop	AU & BS	—	—	no driving
45	10.02.88	Swillington	Sh-pile	Vibro	AU & BS			no driving
46	21.02.88	Scarborough	Sh-pile	Air	AU & AS	DATA32 PDR-B	SSA SSA	Fish dock 2nd record
47	15.03.88	Waltham X	Sh-pile	Hydru	AU & JO	—	—	bad weather, no pile driving
48	17.03.88	Waltham X	Sh-pile	Hydru	AU & JO	DATA33 PDR-C	WSH WHS	Trial piling second record
49	23.03.88	Reston			AU & BS	PDR-D	REV	traffic Measurment
50	09.04.88	Reston	Sh-pile	Vibro	AU & JO	DATA34	RSV	PDR2 failed
51	19.04.88	Rotherhithe	Sh-pile	Vibro	AU & BS	PDR-E,F DATA35	RSV RVS	East-London second record
52	04.05.88	Blaydon	Sh-pile	ABI	AU & JO	DATA35	BLV	Dutton Forshaw
53	06.05.88	Blaydon	H-pile	Air	AU & BS	DATA36	BAH	Area 3
54	07.05.88	Blaydon	H.pile	Hydru	AU & AS	PDR-G	BHH	Area 3
55	12.05.88	Blaydon	H.pile H-pile	Hydrau Hydrau	AU & CH	PDR-H PDR-I	BL PL	Area 3 second pile

Site Visit Dairy

No.	Date	Site	Pile	Hammer	Persons	Disc	File	Comments
56	20.05.88	Aycliffe	—	—	AU & PA	PDR-J	AFB	blast vibration measurement
57	24.05.88	Blaydon	H-pile	Vibro	AU & CH	PDR-K	BFV	Dutton-Forshaw
			H-pile	Hydrau		PDR-L	BB	area 2
58	21.06.88	Aycliffe			AU & PA	PDR-M	AFB	blast vibration
59	28.06.88	Blaydon	H-pile	Air	AU & CH	PDR-O	BLA	Area 2
			H-pile	Hydro		PDR-O	BLY	Area 3
60	29.06.88	Blaydon	H-pile	Hydru	AU & CH	PDR-N	BLN	area 2
61	20.07.88	Blaydon	H-pile	Hydru	AU & CH	PDR-P	BRH	Area 3
			Sh-pile	Air		PDR-Q	BSA	area 3
62	02.08.88	Blaydon	Sh-pile	Diesel	AU & AS	PDR-R	BSD	Area 3
63	05.08.88	Blaydon	H-pile	Hydru	AU & CH	PDR-S	BHD	second part of pile
64	10.08.88	Blaydon	H-pile	Hydru	AU & BS	PDR-T	BHC	CO-OP Site
65	25.08.88	Blaydon			AU & MW			blast measurement
66	30.08.88	Blaydon			AU & BS			blast measurement
67	16.09.88	Blaydon	Sh-pile	Diesel	AU & BS	—	—	North Tyne bank
68	26.09.88	Newark	H-pile	Drop	AU & BS	PDR-U	NDH	1st pile
						PDR-V,W	WDH	2nd pile
69	12.10.88	Flitwick	—	—	AU & AS	—	—	primary visit
70	16.10.88	Flitwick	—	—	AU & BS	—	—	strain gauge on wall A,B
71	17.10.88	Flitwick	H-pile	Drop	AU & AS	PDR-1,3	ABC	wall A tested
72	18.10.88	Flitwick	H-pile	Drop	AU & AS	PDR-4,9	AHD	wall A and B examined
73	19.10.88	Flitwick	H-pile	Drop	AU & AS	PDR-10	CDH	wall B and C
74	20.10.88	Flitwick	H-pile	Drop	AU & AS	PDR-15	DDH	wall D and C
75	21.10.88	Flitwick	Sh-pile	Vibro	AU & BS	PDR-25	DHC	wall D and C
76	25.10.88	Sheffield	H-pile	Diesel	AU & AS	PDR-X	FDH	South River Don
77	27.10.88	Sheffield	H-pile	Diesel	AU & AS	PDR-Y,Z	SDH	North River Don
78	04.11.88	Aycliffe			AU & PA	PDR-a	ABM	Blast Measurement
79	16.11.88	Blaydon	H-pile	Diesel	AU & AS			hammer broken
80	23.11.88	Blaydon	H-pile	Diesel	AS		BHD	Rail line
81	25.11.88	Blaydon	H-pile	Hydru	AU & BS	PDR-b,c,d	BDH	Contract 3
82	16.12.88	Newark	H-pile	Drop	AU & AO	PDR-e,f	NDH	raking pile
83	06.02.89	Newark	H-pile	Drop	AU & AO	PDR-g	NEW	River Trent

Site Visit Dairy

No.	Date	Site	Pile	Hammer	Persons	Disc	File	Comments
84	15.02.89	Newark	Sh-pile	Vibro	AU & AO	PDR-h,i	NSV	corner and single pile
85	22.02.89	Sheffield	H-pile	Diesel	AU & AO			no pile driving
86	23.02.89	Sheffield	H-pile	Diesel	AU & AO	PDR-j,k	SHF	raking pile
87	24.02.89	Sheffield	H-pile	Diesel	AU & AO	—	—	PDR1 failed
88	25.02.89	Sheffield	H-pile	Diesel	AS	—	—	Yellow transducers used
89	02.03.89	G.Yarmouth	—	—	AU & AO			bad weather,no driving
90	03.03.89	G.Yarmouth	Tube	Vibro	AU & AO	PDR-l,m,n	YTV	River bank
91	06.03.89	Aycliffe			AU & AS			blast measurement, missed
92	14.03.89	Blaydon	H.pile	Hydru	AU & AO	PDR-o,p	GHH	contract 3
93	15.03.89	Aycliffe			AU & PA	PDR-q	BVF	blast measurement
94	21.03.89	Blaydon	H-pile	Hydru	AU & AO	PDR-r,s	MHH	Contract 3
95	22.03.89	Darlington			AU & AO	PDR-t	DBV	blast vibration
96	12.05.89	Blaydon	H-pile	Hydr	AO & Mi	PDR-u	BLA	contract 3
97	14.05.89	Blaydon	H-pile	Hydr	AO & Mi	PDR-v	BLA	contract 3
98	15.05.89	Blaydon	H-pile	Hydr	AO & Mi	PDR-w	BLA	contract 3
99	01.06.89	Barrow	Larssen	Delmag D30	AO & Mi	PDR-x	BAR	negligible ppvs
100	06.06.89	Potters Bar	Frod	drop	AO & RB	PDR-y	PBS	
101	06.06.89	Enfield	Lar 25W	BSP DE30C	AO & RB	PDR-z	ENF	
102	06.06.89	Pickets Lock	Lar 25W	BSP D30	AO & RB	PDR-aa	PLC	London clay
103	07.06.89	Southwark Br	Lar 32W	air	AO & RB	PDR-ab	SOU	
104	07.06.89	New B'gate	Fn 3A	Vibro 223	AO & RB	PDR-ac	NBG	
105	08.06.89	Acton	Lar 2	PTC 260E	AO & RB	PDR-ad	ACT	
106	08.06.89	Kenton	Lar 16W	ABI	AO & RB	PDR -ae	KEN	
107	09.06.89	Iver	Lar 16W	Vib 216	AO & RB	PDR -af	IVE	
108	20.06.89	Upminster	Lar 16W	3t drop	AO & RB	PDR-ag	USR	clay/sand
109	20.06.89	Faversham	Lar 16W	3.25t drop	AO & RB	PDR-ah	FAV	silt/clay
110	21.06.89	Aylesbury	Lar 16W	ID 17	AO & RB	PDR-ai	ABI	clay

Site Visit Dairy

No.	Date	Site	Pile	Hammer	Persons	Disc	File	Comments
111	22.06.89	Stevenage	Lar 25W	PE 324	AO & RB	PDR-aj	STE	gravel, clay
112	23.06.89	Burley	Lar	Delm D30	AO & MN	PDR-ak	BUR	
113	13.07.89	St. P's Bas	Lar	ICE vib	AO,AS,MN	PDR-al	–	ICE generator failed
114	20.07.89	Blackpool	Lar 6	Hydr 357 ICE vib	AS & MN	PDR-am PDR-an	BLP BLP	clays and sand bands
115	01.08.89	Ncl Crest	tube	3t drop	AS	-	-	paper trace rcdr
116	31.07.89	Thrapston	Lar 20W	Vibro	AO & RB	PDR-ao	AIM	silty clay
117	01.08.89	Felixstowe	Lar 6	Vibro	AO & RB	PDR-ap	FLX	brown clay
118	01.08.89	Maldon	Lar 12W	air	AO & RB	PDR-aq	MAL	ballast/clay
119	01.08.89	Basildon	Lar 32W	BSP 357	AO & RB	PDR-ar	BAS	brown clay
120	02.08.89	Basildon	Lar 25W	BSP 30C	AO & RB	PDR-as	BBS	brown clay
121	02.08.89	Crawley	Fn 3NA	Hydr	AO & RB	PDR-at	CRA	sandstone
122	02.08.89	Edenbridge	Lar 3	air	AO & RB	PDR-au	EDB	silty clay
123	02.08.89	Gatwick	Lar 20W	Vibro	AO & RB	PDR-av	GAT	
124	03.08.89	Ilford	Lar 25W	vibro diesel	AO & RB	PDR-aw PDR -ax	ILL ILD	London clay London clay
125	20.08.89	Stockton	H pile	Impact dr	AO	PDR-ay	SRC	peaty clay
126	23.08.89	Newcastle	Lar 32W	vibro	AO	PDR-az	SPB	made ground
127	28.08.89	Whickham	st. tubes	drop	AO	-	-	hammer broken
128	04.09.89	Ponteland	concrete	drop	AO	PDR-ba	PON	made ground
129	12.09.89	St Peters B	Lars 6	Kobi 25	AO	PDR-bb	SPB1	fill
130	12.10.89	St Peters B	Lars 6	Kobi 25	AO	PDR-bc	SPB2	fill

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SL : *Stewart Lightbody*
CH : *Chris Hunter*
SR :*Steve Richardson*
MA :*Mahmoud Arta*
MW :*Mike Winter*
MN :*Michele Nixon*

APPENDIX 2

```



'         FILE DM52  -    1st attempt at SmartwareII DM52

public Stand_Off[5]
global $File_name, draw_screen(), counter, $VAD, $Getfile, file_error(1), errortrap(), testing
global datastrip(2), gene, ilast, resulting(2), Stand_Off_Entry(), no_of_stations


main

local i, blank, x
lock module Stand_Off[]

'         Draw opening screen and prompt for target generic filename
label start

$VAD="vadr"
counter=1
ilast=0
label restart
draw_screen()


'                    *************  MAIN FILE LOOP    *************************

for counter = 1 to 4
single-step off

if $File_name=="q"
     message "Returning to calling file, assumed finished - hit any key"
     jump leave_dm52
elseif $File_name=="s"
     beep 1 "Calling Stand-off subroutine"
     Stand_Off_Entry()
     jump leave_dm52
end if

repaint on
$Getfile="c:\smartii\trans\"|mid($VAD,counter,1)|$File_name|".pro"

if file($Getfile)=0
     file_error($Getfile)
     jump start
end if


fopen $Getfile as 1
let gene=str(mid($VAD,counter,1))
if gene="v" or gene="a"
     ilast=7
elseif gene="d"
     ilast=6
```

```
else
     jump read
end if

for i=1 to ilast
     fread 1 into blank
end for

label read

repaint off

for x=1 to 15
fread 1 into testing
if gene="r"
     resulting(testing,$File_name)
     jump result_read
end if
datastrip(testing,$File_name)
label result_read
end for

beep
screen print (15+counter) 15 4 0 $Getfile|" processed"
fclose 1
end for
jump restart
label leave_dm52
execute "dm53"
end main



function draw_screen()

screen clear 15 0
screen print 1 15 15 0 "UNIVERSITY OF DURHAM GROUND VIBRATION DATABASE"
screen print 10 20 15 0 "Enter filename to be analysed {q quits}"
screen input 10 61 15 0 6 $File_name
end function


function file_error(txt)

screen clear 15 0
screen print 10 20 15 0 "File "|txt|" not present in transfer subdirectory"
screen print 12 20 15 0 "Returning for retry"
screen print 20 20 15 0 "Strike any key to continue"
message
end function


function datastrip(txt,$File_name)

data enter blank
[channel number]=value(mid(txt,3,2))
```

```
[Channel value]=value(mid(txt,6,10))
[VAD]=mid($VAD,counter,1)
[Name]=$File_name
end function
function resulting(txt,$File_name)
data enter blank
[VAD]=left(testing,1)
[channel number]=val(mid(testing,4,2))+20
[Channel value]=val(mid(testing,17,10))
[Name]=$File_name
end function
function Stand_Off_Entry()
local i, $val
screen clear 15 0
screen print 1 15 15 0 "UNIVERSITY OF DURHAM GROUND VIBRATION DATABASE"
screen print 4 15 15 0 "How many geophone stations (default 5) :- "
screen input 4 58 15 0 1 no_of_stations 5
screen clear 15 0
screen print 1 15 15 0 "UNIVERSITY OF DURHAM GROUND VIBRATION DATABASE"
for i=1 to val(no_of_stations)
     $val=chr(64+i)
     screen print 6+2*i 15 15 0 "Please enter stand off for station "|$val|":-"
     screen input 6+2*i 54 15 0 2 Stand_Off[i]
end for
end function
function errortrap()
message "Should be debugging, Press any key to continue"
end function
```

```
'     File dm53   --   SmartWareii version 1

external Stand_Off[5]

global $Station, i, x

main
repaint off
order sort execute "dm53s" index "dm53ind"

data goto record first

while (record<=records)

data find [VAD] equal "a" options "i"
[high]="X"
data find [VAD] equal "d" options "i"
[high]="X"
data find [VAD] equal "v" options "i"
[high]="X"
if [Channel Number] = 32
     exit while
end if
data goto record next

end while

data query execute "dm53q" index "dm53qind"

data goto record first

$Station="ABCDE"

for x = 1 to 5
     for i = 1 to 9
          [Stand Off] = Stand_Off[x]
          [Station] = mid($Station,x,1)
          data goto record next
     end for
end for

for x=1 to 5
     for i = 1 to 3
          [Stand Off] = Stand_Off[x]
          [Station] = mid($Station,x,1)
          data goto record next
     end for
end for



repaint on
execute "dm54"
end main
```

```
'    File DM54 - Sends data to spreadsheet to be analysed
public plotg
main

local choice
label begining

screen clear 0 0
screen print 1 20 15 0 "SPREADSHEET DATA ANALYSIS ROUTINES"
screen print 10 20 15 0 "1. Curve fit current data and return."
screen print 12 20 15 0 "2. Curve fit data, graph then return."
screen print 14 20 15 0 "3. Return to main menu."
screen print 20 20 15 0 "Enter choice  ..."
screen input 20 38 15 0 1 choice mask "[123]"

if choice = 3
     exit main
elseif choice = 2
     plotg="go"
end if

'          *****  Sorts the data in the correct order for processing in
'          *****  spreadsheet module

order sort execute "dm54s" index "dm54ind"
order change index "dm54ind"

data send spreadsheet row-format [1;2;Stand Off] project-file "bill"
```

```

global i, trans[48]

main
local $Stat_A, $Stat_E

fopen "c:\smartii\spread\data_go.dat" as 1
file load custom-view "ground_v"

for i=1 to 48
     fread 1 into trans[i]
end for

fread 1 into $Stat_A
fread 1 into $Stat_E

fclose 1

data enter blank

[25]=trans[1]
[26]=trans[2]
[27]=trans[3]
[28]=trans[4]
[29]=trans[5]
[30]=trans[6]
[31]=trans[7]
[32]=trans[8]
[33]=trans[9]
[34]=trans[10]
[35]=trans[11]
[36]=trans[12]
[37]=trans[13]
[38]=trans[14]
[39]=trans[15]
[40]=trans[16]
[41]=trans[17]
[42]=trans[18]
[43]=trans[19]
[44]=trans[20]
[45]=trans[21]
[46]=trans[22]
[47]=trans[23]
[48]=trans[24]
[49]=trans[25]
[50]=trans[26]
[51]=trans[27]
[52]=trans[28]
[53]=trans[29]
[54]=trans[30]
[55]=trans[31]
[56]=trans[32]
[57]=trans[33]
[58]=trans[34]
[59]=trans[35]
[60]=trans[36]
[61]=trans[37]
```

```
[62]=trans[38]
[63]=trans[39]
[64]=trans[40]
[65]=trans[41]
[66]=trans[42]
[67]=trans[43]
[68]=trans[44]
[69]=trans[45]
[70]=trans[46]
[71]=trans[47]
[72]=trans[48]
dbput("[Stat_A]",$Stat_A)
dbput("[Stat_E]",$Stat_E)
data update only-one
clear global
end main
```

APPENDIX 3

Ground Vibration Database - Attenuation Report

Request Date 30/10/1990

Site Location	- Newark (Relief Road)	**Date of Visit**	- 16 December 88
Hammer Type	- Hyd Drop	**Pile Type**	- H Pile
Hammer Model	- Banut 400 (5 tonne)	**Pile Section**	- 305*305*186 kg/m
Nominal Energy	- 24.5 kJ	**Pile Length**	- 12 m.
		Toe Depth	- A
Ground Type	- Silty Clay	**Rake**	- Y
Classification	-	**Record Number**	- 67

Stand Off (m)	Resultant Velocity (mm/s)
2	32.7
3	25.8
5	15.5
6	11.8
7	9.0
8	6.9
10	4.6
11	4.1
12	4.0
14	4.2
15	4.4
16	4.4

Comments

Raking 1:4

Ground Vibration Database - Attenuation Report

Request Date 29/10/1990

Site Location	- Newark (Relief Road)	**Date of Visit**	- 16 December 88
Hammer Type	- Hyd Drop	**Pile Type**	- H Pile
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Stand Off (m)	Resultant Velocity (mm/s)
2	32.7
3	25.8
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6	11.8
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10	4.6
11	4.1
12	4.0
14	4.2
15	4.4
16	4.4

Comments

Raking 1:4

APPENDIX 4

Least Squares Cubic Equations and Matrix Solution

It can be shown that for a cubic polynomial

$$a.n+b\Sigma x+c\Sigma x^2+d\Sigma x^3=\Sigma y$$
$$a\Sigma x+b\Sigma x^2+c\Sigma x^3+d\Sigma x^4=\Sigma x.y$$
$$a\Sigma x^2+b\Sigma x^3+c\Sigma x^4+d\Sigma x^5=\Sigma x^2 y$$
$$a\Sigma x^3+b\Sigma x^4+c\Sigma x^5+d\Sigma x^6=\Sigma x^3 y$$

which can be represented in matrix form as:-

$$\begin{bmatrix} n & \Sigma x & \Sigma x^2 & \Sigma x^2 \\ \Sigma x & \Sigma x^2 & \Sigma x^3 & \Sigma x^4 \\ \Sigma x^2 & \Sigma x^3 & \Sigma x^4 & \Sigma x^5 \\ \Sigma x^3 & \Sigma x^4 & \Sigma x^5 & \Sigma x^6 \end{bmatrix} \begin{bmatrix} \Sigma y \\ \Sigma xy \\ \Sigma x^2 y \\ \Sigma x^3 y \end{bmatrix}$$

gives

$$\begin{bmatrix} a \\ b \\ c \\ d \end{bmatrix}$$

APPENDIX 5

```
'     File DMM - Support file for Ground Vibration Database

'     Any alteration of the original source code would inevitabley lead
'     to the disowning of the software by Durham University and the full
'     acceptance by British Steel of the consequences of their actions.

'     Written by A Oliver in January 1990

'     Originally designed for the sole use of British Steel

'     Brief description of each function lies at its begining.

'     ******    Declarations

public Names[12,3], gen[15,5], $t2

global select(), initial(), choice(), Build_Query(), View_Menu(), browse()
global blank(), $size, $here_it_is, view(), hardcopy(), $count, Leaving()
global Wipe_out(), $xx, placing(), view_rec(1), $warning
global flag_on(), flag_off(), $flag2, $max, $min, $upper, size(), prep()
global index_only_one(), $t1, $t3,pop_up(), $form

main

repaint off
single-step off
f1help off

'     ******    Ensures no error if file already loaded

error off
file load custom-view "ground_v"
if cerror>0 and not (cerror = 3618)
     errormessage cerror "Problem loading main datafile, seek assistance"
end if
error on

lock module gen[]
```

```
screen clear 15 0

initial()
choice()


end main






'                                          *******     SELECT      ***
****
'    ******  Draws the main screen
function select()




screen print 2 20 14 0 "GROUND VIBRATION DATABASE - MAIN MENU"
screen print 3 20 14 0 "-------------------------------------"
screen print 4 3 14 0 today
screen print 4 58 14 0 "Current time "|time

screen draw box 5 1 13 51 6 0

screen draw box 13 1 19 51 6 0

screen draw box 5 51 31 80 6 0

screen draw box 1 1 31 80 6 0


screen print 6 2 14 0 "1. "|Names[1,1]
screen print 6 30 14 0 " 7. "|Names[7,1]
screen print 7 2 14 0 "2. "|Names[2,1]
screen print 7 30 14 0 " 8. "|Names[8,1]
screen print 8 2 14 0 "3. "|Names[3,1]
screen print 8 30 14 0 " 9. "|Names[9,1]
screen print 9 2 14 0 "4. "|Names[4,1]
screen print 9 30 14 0 "10. "|Names[10,1]
screen print 10 2 14 0 "5. "|Names[5,1]
screen print 10 30 14 0 "11. "|Names[11,1]
screen print 11 2 14 0 "6. "|Names[6,1]
screen print 11 30 14 0 "12. "|Names[12,1]

screen print 21 5 14 0 "**  Selection Codes **            "
screen print 23 5 14 0 "n - Selection code from 1 to 12   "
screen print 24 5 14 0 "V - View menu      "
screen print 25 5 14 0 "P - Print menu                    "
screen print 26 5 14 0 "S - Runs current selection        "
screen print 27 5 14 0 "C - Clear current selections      "
screen print 28 5 14 0 "Q - Quit program, exit to Smart   "

blank()
```

```
end function



'                                                  *******  INITIAL     **********


'     ******  Initialises field names in array Names[] and sets Names[n,3]
'     ******  to 99. If its value ever drops below this a selection must have
'     ******  been made on that field.



function initial()

local i
Names[1,1]="[Site Location (1)]"
Names[2,1]="[Hammer Type]"
Names[3,1]="[Hammer Model]"
Names[4,1]="[Notional Energy (kJ)]"
Names[5,1]="[Ground Type]"
Names[6,1]="[Classification]"
Names[7,1]="[Pile Type]"
Names[8,1]="[Pile Section]"
Names[9,1]="[Pile Length (m)]"
Names[10,1]="[Toe Depth]"
Names[11,1]="[Rake]"
Names[12,1]="[Record No]"
for i=1 to 12
     let Names[i,3]=99
end for
$count = 99
$warning = 0
order change physical
$size=str(precords)
end function




'                                                  *******  CHOICE    ***********
'     ******  Choice is the main menu routine
'     ******  A number enters a selection code and then runs PLACING
'     ******  S builds the query and executes it on current selections
'     ******  V starts the view menu
'     ******  P starts the print menu
'     ******  Q Quits through LEAVING
'     ******  C Clears the current selection

function choice()

label selection
screen print 4 58 14 0 "Current time "|time
if records<precords
```

```
     screen print 30 21 14 0 "Records currently selected "|$size
end if
screen clear box 20 2 29 50 14 0 no-border
select()

screen print 15 2 14 0 "   Please enter selection "
screen input 15 28 14 0 2 $XX
if $xx=="q"
     screen clear box 14 2 18 50 14 0 no-border
     Leaving()
     jump selection
elseif $xx=="s"
     Build_query()
     jump selection
elseif $xx=="p"
     screen clear box 20 2 29 50 14 0 no-border
     hardcopy()
     if $count<99
          screen shortrestore $here_it_is
          order change index "dmmind"
     end if
     jump selection
elseif $xx=="v"
     screen clear box 20 2 29 50 14 0 no-border
     View_Menu()
     screen clear 15 0
     if records<precords
          screen shortrestore $here_it_is
     end if
     jump selection
elseif $xx=="c"
     Wipe_out()
     screen clear box 20 2 30 50 14 0 no-border
     jump selection
elseif val($xx)>12 or val($xx)<1
     jump selection
else
     placing()
     jump selection
end if


screen clear box 14 2 18 50 14 0 no-border

end function




'                                        ********   BUILD-QUERY *******

'    ******  Checks that Names[n,3]<99 and if it is it writes an appropriate
'    ******  line to a query file. Different fields require different formats
'    ******  NHE and pile length search over a 25% range.
```

```

function Build_Query()

local i

screen clear box 20 2 30 50 14 0 no-border


if file ("dmmsel.dfq")=1
     tools file erase "dmmsel.dfq"
end if

fopen "dmmsel.dfq" as 1

if Names[1,3]<99
     fwrite 1 from str(Names[1,1])|" ! "|Names[1,2]|" and"
end if

if Names[2,3]<99
     fwrite 1 from str(Names[2,1])|" ! "|Names[2,2]|" and"
end if

if Names[3,3]<99
     fwrite 1 from str(Names[3,1])|" ! "|upper(Names[3,2])|" and"
end if

if Names[4,3]<99
     fwrite 1 from "(0.75*"|Names[4,2]|"<="|str(Names[4,1])|") and ("|str(Names[4,1])|"<= 1.25*"|Names[4,2]|") and"
end if

if Names[5,3]<99
     fwrite 1 from str(Names[5,1])|" ! "|Names[5,2]|" and"
end if

if Names[6,3]<99
     fwrite 1 from str(Names[6,1])|" ! "|Names[6,2]|" and"
end if

if Names[7,3]<99
     fwrite 1 from str(Names[7,1])|" ! "|Names[7,2]|" and"
end if

if Names[8,3]<99
     fwrite 1 from str(Names[8,1])|" ! "|Names[8,2]|" and"
end if

if Names[9,3]<99
     fwrite 1 from "(0.75*"|Names[9,2]|"<="|str(Names[9,1])|") and ("|str(Names[9,1])|"<= 1.25*"|Names[9,2]|") and"
end if

if Names[10,3]<99
     fwrite 1 from str(Names[10,1])|" == "|Upper(Names[10,2])|" and"
end if

if Names[11,3]<99
```

```
     fwrite 1 from str(Names[11,1])|" == "|Upper(Names[11,2])|" and"
end if

if Names[12,3]<99
     fwrite 1 from str(Names[12,1])|" = "|Names[12,2]|" and"
end if

fwrite 1 from "[Record No] > 0"

fclose 1

tools file erase "dmmind.idx"

screen print 23 5 14 0 "Query being processed, please wait ..."
if records<precords
     screen print 30 7 14 0 "Original query held "|$size| " records"
end if
order change physical

'    ******  Qeury executed and $size set to no. of records selected

data query execute "dmmsel.dfq" index "dmmind.idx"
$size=str(records)
if val($size)=0
     let $size="***"
end if

error off

order change index "dmmind"

'    ******  Test for error on index, means no records selected

if (cerror<>0)
     beep 2
     screen clear box 21 2 23 38 14 4 NO-Border
     screen print 21 9 14 4 "No records in database match "
     screen print 22 9 14 4 "   your selection criteria"
     screen print 23 9 14 4 "      Any key to continue..."
     wait 200
     screen clear box 21 4 30 50 14 0 NO-Border
end if
error on

if records < precords
     screen clear box 14 2 18 50 14 0 no-border
     screen clear box 21 4 30 50 14 0 NO-Border
     screen print 30 21 14 0 "Records currently selected "|$size
end if

end function




'                                        ********    VIEW-MENU   *****
**
```

```
'     ******  Calls browse or view

function View_Menu()
local $pp, $rec
label top_menu
screen clear box 21 4 30 49 14 0 NO-Border
screen print 21 5 14 0 "**  VIEW MENU  **                                              "
screen print 23 5 14 0 "1. View Summary screen                                         "
screen print 24 5 14 0 "2. View Full Record screens                                    "
screen print 25 5 14 0 "3. View Velocity Report                                        "
screen print 26 5 14 0 "9. Quit view menu                                              "
screen print 28 5 14 0 " Please enter choice :-"
screen input 28 28 14 0 1 $pp mask "[1239]"
$pp=val($pp)
if $pp=1
      browse()
      screen clear 15 0
      return
elseif $pp=2
      view()
      screen clear 15 0
      return
elseif $pp=3
      label rec_again_3
      screen clear box 21 4 30 49 14 0 NO-Border
      screen print 28 5 14 0 "Enter Record No. to be viewed "
      screen print 29 5 14 0 "[Q quits]"
      screen input 28 36 14 0 3 $rec
      if $rec=="q"
          screen clear box 21 4 30 49 14 0 NO-Border
          jump top_menu
      elseif value($rec) > precords
          jump rec_again_3
      end if
      repaint off
      flag_on()
      pop_up()
      if $t1="xxx"
          jump top_menu
      end if
      prep()
      order change physical
      data goto record record-number val($rec)
      view_rec(precords)
      flag_off()
      screen clear 15 0
      jump top_menu
else
      return
end if

end function



'                                             ********    BROWSE    ******
**
```

```

'     ******  displays the listed fields in browse format and allows the
'     ******  to move from record to record very easily. A record is
'     ******  chosen and can be examined in greater detail including
'     ******  on screen reports. All driven from inchar. The report printed
'     ******  is in draft mode using standard fonts, for speed only

function browse()

'                    The Immortal Browse Screen

local $x, Percent_0, $choice, $curr_rec_no
label still_browse

repaint on
data browse fields [Hammer Type;Pile Type;Ground Type;Toe Depth;Record No]
label retry
blank()
screen draw box 32 1 35 80 15 0
screen print 33 2 14 0 "Enter = select  "|chr(24)|"=prev rec    PgUp=Previous screen    Ctrl Home=first record"
screen print 34 2 14 0 "  X   = exit    "|chr(25)|"=next rec    PgDn=Next screen          Ctrl End =last record"
let $x=oldkey(inchar)

if not($x=18432 or $x=20480 or $x=13 or $x=18688 or $x=20736 \
       or $x=30464 or $x=29952 or $x=120 or $x=88)
     jump retry
end if

if $x = 18432
     data goto record previous
     jump retry
elseif $x = 20480
     data goto record next
     jump retry
elseif $x = 18688 and record - 20 > 0
     Percent_0 = record - 20
     data goto record record-number Percent_0
     jump retry
elseif $x = 18688 and record - 20 <= 0
     data goto record record-number 1
     jump retry
elseif $x = 20736 and record + 20 <= records
     Percent_0 = record + 20
     data goto record record-number Percent_0
     jump retry
elseif $x = 20736 and record + 20 > records
     Percent_0 = records
     data goto record record-number Percent_0
     jump retry
elseif $x = 30464
     data goto record record-number 1
     jump retry
elseif $x = 29952
```

```
     Percent_0 = records
     data goto record record-number Percent_0
     jump retry
elseif $x=120 or $x=88
     jump returning
end if

screen clear 15 0
blank()
data browse off
label brloop2
screen draw box 32 1 35 80 15 0
screen print 33 2 14 0 "    X = returns to main menu       PgUp = "|chr(24)|" screen     P = print reports"
screen print 34 2 14 0 "enter = return to browse screen    PgDn = "|chr(25)|" screen     V =  view reports"

let $x=inchar
if not($x=120 or $x=88 or $x=112 or $x=80 or $x=749 \
     or $x=118 or $x=86 or $x=329 or $x=337)
     jump brloop2
end if

if $x=120 or $x=88
     jump returning
elseif $x=112 or $x=80
     $curr_rec_no=precord
     pop_up()
     if $t1=="xxx"
          jump brloop2
     end if
     prep()
     if $t1=="xxx"
          jump brloop2
     end if
     flag_on()
     index_only_one()
     blank()
     print report execute "quick" printer detail start "1" end "1" copies "1"
     flag_off()
     data goto record record-number $curr_rec_no
     jump brloop2
elseif $x=118 or $x=86
     pop_up()
     if $t1=="xxx"
          jump brloop2
     end if
     prep()
     if $t1=="xxx"
          jump brloop2
     end if
     view_rec(precord)
     blank()
     screen clear 15 0
     repaint
     jump brloop2
```

```
elseif $x=329
     data goto page previous
     jump brloop2
elseif $x=337
     data goto page next
     jump brloop2
else
     jump still_browse
end if

label returning
repaint off
data browse off
screen clear 15 0
end function




'                                               *******    VIEW    *********
'    ******  Allows the user to look at records one by one and print the same
'    ******  reports as browse.

function view()
local $x, Percent_0, $pos

screen clear 15 0
label loopy
repaint on
data browse off

blank()
screen draw box 32 1 35 80 15 0
screen print 33 2 14 0 chr(26)|" Next Record     P = Print reports    PgUp = Goto top screen    X = main"
screen print 34 2 14 0 chr(27)|" Prev Record     V = View reports     PgDn = Goto bottom screen     menu"
$x = oldkey(inchar)
if not($x=120 or $x=88 or $x=19712 or $x=112 or $x=80 or $x=118 or $x=86 \
     or $x=19200 or $x=20736 or $x=18688)
     jump loopy
end if

if $x=19712
     data goto record next
     jump loopy
elseif $x=19200
     data goto record previous
     jump loopy
elseif $x=20736
     if $pos>=1
          jump loopy
     else
          $pos=$pos+1
     end if
```

```
          data goto page next
          jump loopy
elseif $x=18688
          if $pos=1
               $pos=$pos-1
          end if
          data goto page previous
          jump loopy
elseif $x=112 or $x=80
          flag_on()
          pop_up()
          if $t1=="xxx"
                jump loopy
          end if
          prep()
          if $t1=="xxx"
                jump loopy
          end if
          index_only_one()
          blank()
          print report execute "quick" printer detail start "1" end "1" copies "1"
          flag_off()
          blank()
          repaint
          jump loopy
elseif $x=118 or $x=86
          pop_up()
          if $t1=="xxx"
               jump loopy
          end if
          prep()
          if $t1=="xxx"
               jump loopy
          end if
          view_rec(record)
          blank()
          repaint
          jump loopy
elseif $x=120 or $x=88
          data goto page previous
          $pos=0
end if

repaint off
end function



'                                                  ******** HARDCOPY  *******
'         ******  Allows the user to print a full report ie rad, tra, ver and res
'         ******  or just the resultant. These reports use line graphics and so
'         ******  take quite a while but produce a good quality document
function hardcopy()
```

```

local $pp, $well, $rec, i, $fred
label start_print
screen print 21 5 14 0 "**  PRINT MENU  **"
screen print 23 5 14 0 "1. Velocity Attenuation Report [Res only]  "
screen print 24 5 14 0 "2. Full analysis report        [All comp]  "
screen print 26 5 14 0 "9. Quit print reports                      "
screen print 28 5 14 0 " Please enter choice :-"
screen input 28 28 14 0 1 $pp mask "[129]"
$pp=val($pp)
if $pp=1
      screen clear box 21 4 30 49 14 0 NO-Border
      screen print 22 5 14 0 $size|" records to be printed, OK?"
      screen input 22 35 14 0 1 $well mask "[YyNn]"
      if $well=="y"
          screen print 24 5 14 0 "Reports will take a few minutes to produce"
          screen print 25 5 14 0 "Please wait ..."
          print report execute "single" printer detail start "1" end "1" copies "1"
          screen clear box 21 4 29 49 14 0 NO-Border
      else
          label rec_again_2
          screen clear box 21 4 30 49 14 0 NO-Border
          screen print 28 5 14 0 "Enter Record No. to be printed "
          screen print 29 5 14 0 "[Q quits]"
          screen input 28 37 14 0 3 $rec
          if $rec=="q"
              screen clear box 21 4 30 49 14 0 NO-Border
              jump start_print
          elseif value($rec) > precords
              jump rec_again_2
          else
               data goto record record-number value($rec)
          end if
          repaint off
          flag_on()
          index_only_one()
          size()
          $t1="VEL"
          prep()
          print report execute "single" printer detail start "1" end "1" copies "1"
          flag_off()
          blank()
          screen clear box 21 4 29 49 14 0 NO-Border
          jump start_print
      end if
      return
elseif $pp=2
      screen clear box 21 4 30 49 14 0 NO-Border
      screen print 22 5 14 0 $size|" records to be printed, OK?"
      screen input 22 36 14 0 1 $well mask "[YyNn]"
      if $well=="n"
          label rec_again_3
          screen clear box 21 4 30 49 14 0 NO-Border
          screen print 28 5 14 0 "Enter Record No. to be printed "
```

```
            screen print 29 5 14 0 "[Q quits]"
            screen input 28 37 14 0 3 $rec
            if $rec=="q"
                screen clear box 21 4 30 49 14 0 NO-Border
                jump start_print
            elseif value($rec) > precords
                jump rec_again_3
            else
                data goto record record-number value($rec)
            end if
            repaint off
            flag_on()
            index_only_one()
            size()
            pop_up()
            if $t1="xxx"
                 jump start_print
            end if
            prep()
            print report execute "so" printer detail start "1" end "1" copies "1"
            flag_off()
            blank()
            screen clear box 21 4 29 49 14 0 NO-Border
            jump start_print
        end if
        pop_up()
        $fred=999
        screen clear box 21 4 28 49 14 0 NO-Border
        screen print 24 5 14 0 "Reports will take a few minutes to produce"
        screen print 25 5 14 0 "Please wait ..."
        data goto record record-number 1
        label prloop
        if $fred=record
            jump out
        end if
        let $fred=record
        flag_on()
        index_only_one()
        prep()
        if $t1="xxx"
            jump start_print
        end if
        print report execute "so" printer detail start "1" end "1" copies "1"
        flag_off()
        data goto record next
        jump prloop
        label out
        return
else
        screen clear box 21 4 28 49 14 0 NO-Border
        return
end if

end function
```

```



'                                        ********   LEAVING    ******
'    ******  Leaves the system and sets all required parameters to their
'    ******  required positions

function Leaving()

local $leave
$leave="y"
screen clear box 14 2 18 50 14 0 no-border
screen print 15 5 14 0 "Are you sure you wish to exit system ?"
screen input 15 43 14 0 1 $leave mask "[YyNn]"
if $leave == "n"
     screen clear box 14 2 18 50 14 0 no-border
     beep 1
     return
else
     clear public, public[]
     stop
     f1help on
end if

end function



'                                    *********    WIPE_OUT ******
'    ******  Clears the screen and re-initialises
function Wipe_out()

screen print 15 10 14 0 "                               "
screen clear box 5 51 31 80 14 0
screen draw box 5 51 31 80 6 0
screen clear box 14 2 18 50 14 0 no-border
initial()

end function



'                                    **********     BLANK  ********
'    ****** blanks the lower 7 lines of the screen
function blank()

screen print 32 1 15 0 "                                                  "
screen print 33 1 15 0 "                                                  "
screen print 34 1 15 0 "                                                  "
screen print 35 1 15 0 "                                                  "
screen print 36 1 15 0 "                                                  "
```

```
screen print 37 1 15 0 "                                                                              "
screen print 38 1 15 0 "                                                                              "

end function







'                                                    *******  PLACING    ***********
'     ******  Routine called from main menu and handles the screen writting
'     ******  and array building for the build-query. Names[n,2] contains the
'     ******  actual value to be searched for.Warning on more than 8 selections
'     ******  $count is the important variable, handles screen position,
'     ******  selection count and more!
function placing()

local $ZZ, $old_count, $flag, $x, $yy

if $count=99
     $count = -3
end if


$count=$count+3
$warning=$warning+1

if $warning=8
      beep 5
      screen clear box 14 2 18 50 14 0 no-border
      screen print 15 5 14 4 "WARNING - Too many selection criteria"
      screen print 16 5 14 4 "Clear current selection and start again"
      screen print 17 5 14 4 "      Any key to continue ..."
      label waiting2
      $x=inchar
      while $x < 0
          jump waiting2
      end while
      screen clear box 14 2 18 50 14 0 no-border
end if

$xx=val($XX)
if Names[$XX,3]<99
     let $old_count=$count
     let $count=Names[$XX,3]
     let $flag=1
     screen print (7+$count) 52 14 0 "                              "
else
     let Names[$XX,3]=$count
```

```
end if

screen print (6+$count) 53 14 0 Names[$XX,1]
screen print 15 2 14 0 "Please enter "|Names[$xx,1]|" below :-"
screen print 18 10 14 0 "==> "
screen input 18 15 14 0 30 $YY
screen clear box 14 2 18 50 14 0 no-border
if $XX=4 or $XX=9 or $xx=12
     Names[$XX,2]=$yy
elseif $XX=3
     $yy=upper($YY)
     Names[$XX,2]=""""|$yy|""""
else
     $yy=Proper($YY)
     Names[$XX,2]=""""|$yy|""""
end if
screen print (7+$count) 79-(len($YY)) 15 0 $YY
screen clear box 20 2 30 50 14 0 no-border
screen print (8+$COUNT) 53 14 0 "-------------------------"
screen clear box 14 2 18 50 14 0 no-border

if $flag>0
     $count=$old_count-3
     $flag=0
end if

screen save 5 51 31 80 $here_it_is

end function



'**                                          *************  VIEW_REC  ********
'     ****** Draws the velocity report on the screen

function view_rec(rec)

local i, $x, $a, $b, $c, $d, $pp
screen clear 15 0 no-border
blank()
screen print 3 2 14 0 format "M78" "GROUND VIBRATION DATABASE - VELOCITY
: ATTENUATION REPORT"
screen print 6 2 14 0 "Record Number  = "|str([Record No])
screen print 6 45 14 0 "Pile Type    = "|[Pile Type]
screen print 7 2 14 0 "Hammer Type    = "|[Hammer Type]
screen print 7 45 14 0 "Pile Section = "|[Pile Section]
screen print 8 2 14 0 "Hammer Model   = "|[Hammer Model]
screen print 8 45 14 0 "Pile Length  = "|str([Pile Length (m)])|" m."
screen print 10 2 14 0 "Ground Type    = "|[Ground Type]
screen print 10 45 14 0 "Toe Depth    = "|upper([Toe Depth])
screen print 11 2 14 0 "Classification = "|[Classification]
screen print 11 45 14 0 "Location     = "|[Site Location (1)]

screen print 15 6 14 0 "Dist       Radial       Transverse        Vertica
: l       Resultant"
screen print 16 6 14 0 " (m)"
screen print 16 12 14 0 $t2
```

```
screen print 16 28 14 0 $t2
screen print 16 44 14 0 $t2
screen print 16 60 14 0 $t2

screen draw box 14 5 17 75 14 0
screen draw box 14 5 33 11 14 0
screen draw box 14 5 33 27 14 0
screen draw box 14 5 33 43 14 0
screen draw box 14 5 33 59 14 0
screen draw box 14 5 33 75 14 0

for i = 1 to $upper
     screen print 17+i 7 14 0 format "0m3" gen[i,1]
     screen print 17+i 16 14 0 format $form gen[i,2]
     screen print 17+i 32 14 0 format $form gen[i,3]
     screen print 17+i 48 14 0 format $form gen[i,4]
     screen print 17+i 64 14 0 format $form gen[i,5]
end for
screen print 34 25 14 0 "Any key to continue"
label waiting
$x=inchar
while $x<0
     jump waiting
end while








end function
'                                             *******   FLAG_ON   ********
'    ******  Flags if a selection has been made ie $count will have changed
'    ******  its initial value. Used when a temporary index is to be used

function flag_on()

if $count < 99
     $flag2=1
end if

end function


'                                             *******   FLAG_OFF   ********
'    ******  Changes back to original index
function flag_off()

if $flag2=1
     order change index "dmmind"
     $flag2=0
else
```

```
     wipe_out()
end if

end function

'                                       ***************   PREP  *********
'    ******  Prep builds up the gen[] array which handles the 4 column reports
'    ******  and also checks for less than zero and tail raise.
'    ******  $x always ensures 15 points
function prep()
local i, $a, $b, $c, $d, j, $x
clear gen[]

for  i = 1 to 4
     case(i)
          when 1
               $t3="RAD"
          when 2
               $t3="TRA"
          when 3
               $t3="VER"
          when 4
               $t3="RES"
     end case

     size()

     $a="[A-"|$t3|"-"|$t1|"]"
     $b="[B-"|$t3|"-"|$t1|"]"
     $c="[C-"|$t3|"-"|$t1|"]"
     $d="[D-"|$t3|"-"|$t1|"]"

     $a=DBGET($a)
     $b=DBGET($b)
     $c=DBGET($c)
     $d=DBGET($d)

     gen[1,1]=$min
     gen[1,i+1]=$a+$b*gen[1,1]+$c*gen[1,1]^2+$d*gen[1,1]^3

     for j=2 to $upper
          let $x=round(($max-$min)/($upper-1)*(j-1),0)
          let gen[j,1]=$min+$x
          let gen[j,i+1]=$a+$b*gen[j,1]+$c*gen[j,1]^2+$d*gen[j,1]^3
          if gen[j,i+1]<0
               gen[j,i+1]=0
          end if
     end for

     if gen[($upper-1),i+1]>gen[($upper-2),i+1]
          gen[($upper-1),i+1]=gen[($upper-2),i+1]*0.92
     end if

     if gen[$upper,i+1]>gen[($upper-1),i+1]
          gen[$upper,i+1]=gen[($upper-1),i+1]*0.92
     end if
```

```
end for
end function
'                                        ***********   SIZE   ******* ***
'    ******  Calcs the no. of points between GeoPhone position A & E in m's
'    ******  if its less than 15, used for gen[]
function size()
$max=[Stat_E]
$min=[Stat_A]
if ($max-$min) < 15
     let $upper=$max-$min
else
     let $upper=15
end if
'                                        ************  INDEX_ONLY_ONE  ***
'    ******  Writes an index file of 1 record directly
end function
function index_only_one()
local buff
if file("onlyone.idx")
     tools file erase "onlyone.idx"
end if
buffer buff size 512
pack buff "L" 1
pack buff ">4ss" "datacube"
pack buff ">64sL" precord
fopen "c:\smartii\data\onlyone.idx" as 1
fwrite 1 binary 0 from buff
fclose 1
order change index "onlyone"
end function
'                                        ***********   POP_UP   ***** ***
'    ******  Produces pop up menu for VAD selection
function pop_up()
local $x, $view_it
screen save 13 25 22 55 $view_it
screen clear box 13 25 22 55 14 1
screen print 15 27 14 1 "1. Velocity"
screen print 16 27 14 1 "2. Acceleration"
screen print 17 27 14 1 "3. Displacement"
screen print 18 27 14 1 "9. Quit"
screen print 21 27 14 1 "Please enter choice "
screen input 21 48 14 1 1 $x mask "[1239]"
$x=value($x)
case($x)
```

```
        when 1
             $t1="VEL"
             $t2=" Vel. (mm/s)"
             $form="1M5"
        when 2
             $t1="ACC"
             $t2="Accl. (mm/s)"
             $form="0M5"
        when 3
             $t1="DIS"
             $t2="Disp.  (mm) "
             $form="3M5"
        when 9
             $t1="xxx"
             screen shortrestore $view_it
             return
   end case

   if ([Disc Code] ! "DATA" and $t1="ACC") or ([Disc Code] ! "DATA" and $t1=
   "DIS")
        screen clear box 13 25 22 55 14 1
        screen print 16 26 14 1 format "M28" "Acceleration"
        screen print 17 26 14 1 format "M28" "and"
        screen print 18 26 14 1 format "M28" "Displacement"
        screen print 19 26 14 1 format "M28" "data not available"
        screen print 20 26 14 1 format "M28" "for this record"
        screen print 22 26 14 1 format "M28" "Any key to continue"
        $t1="XXX"
        wait 20
   end if
   screen shortrestore $view_it
   clear $view_it

   end function
```

APPENDIX 6

```
global scroll(2), validate(), verify_load(), v[24,25], $result, $dd, checks()
global $ind, $flag, screen_pop(), help_ver(), $screen, Energy_req_air
global section, depth, p_type, g_type, g_cond, v_lim, v_dis, Sheet_2, limit()
global Energy_req_dsl, Energy_req_drp, Energy_req_vib, $pref_hammer,$type
global bottom, menu(1),Vibro, Air, Diesel, Drop, $res, ch_ham(), ans, $mass
global v_screen(), $sec, $limit, BSP_mod, tr[16,2], vv[10,6], $pref_en
global stop_it, $rating_di, $rating_dr, $rating_vi, blanker(), s_or_p(), $unit
global comm, vib_comm
main
local i, ans1, $x, $temp, $temp_2, $choice
single-step off
repaint off
error off
file load custom-view "hammers.vw"
file load custom-view "s_e.vw"
error on
label start
$limit=""
$pref_en=""
BSP_mod=1
stop_it=""
screen clear 0 3 no-border
screen print 21 1 15 3 "                                                                                "
screen print 22 1 15 3 "                                                                                "
screen print 23 1 15 3 "                                                                                "
screen print 24 1 15 3 "                                                                                "
screen print 25 1 15 3 "                                                                                "
screen clear box 4 11 10 69 0 0
screen save 12 1 25 78 $screen
screen print 1 1 14 3 format "m80" "GROUND VIBRATION EXPERT SHELL SYSTEM"
screen draw box 4 11 10 69 8 8
scroll("Loading Verification Data...",6)
verify_load()
'          *****    THIS ALWAYS CLEARS THE DIALOGUE BOX
scroll("Please enter the pile type [ (S)heet or (B)earing ]",6)
screen input 7 36 15 8 8 p_type
$ind=1
validate(p_type)
p_type=Proper($result)
screen shortrestore $screen
screen print 7 36 15 8 p_type
milli-wait 500

s_or_p()

screen clear box 7 30 8 50 0 0 no-border
```

```
scroll("Do you know the pile section [ y or n] ?",6)
screen input 7 39 15 8 1 ans mask "[yYnN]"
if ans == "n"
     if p_type=="sheet"
          section=3
          $sec=6
     else
          section="305*305*110"
          $mass="110"
     end if
     jump depth
end if

scroll("What is the pile section ?",6)
screen input 7 36 15 8 7 section
validate(section)

if $ind=2
     screen shortrestore $screen
'    screen clear box 10 30 11 50 0 0
     section=$result
     jump depth
end if

screen shortrestore $screen
screen clear box 7 30 8 50 0 0 no-border
section=str(v[2*$ind-1,Value($result)+2])
scroll("What is the unit mass of the bearing pile ?",6)
screen input 7 38 15 8 3 ans
$ind=$ind+value($result)
validate(ans)
screen shortrestore $screen
$mass=value($result)
section=proper(section|"*"|str($mass))
screen print 7 38 15 8 section
milli-wait 500

label depth
scroll("What is the pile penetration in metres ( 2 digits ) ?",6)
screen input 7 38 15 8 3 depth mask "##"
screen clear box 7 30 8 50 0 0 no-border
screen print 7 38 15 8 depth
$dd=value(depth)
if value(depth) <= 12 and p_type=="sheet"
     depth="L"
elseif value(depth) > 12 and p_type=="sheet"
     depth="G"
end if

milli-wait 500

scroll("What type of ground is to be piled?",6)
screen input 7 36 15 8 10 g_type
$ind=9
validate(g_type)
g_type=Proper($result)
screen clear box 7 30 8 50 0 0 no-border
```

```
screen shortrestore $screen
screen print 7 36 15 8 g_type
milli-wait 500

if g_type="Granular"
     $ind=11
else
     $ind=10
end if

scroll("And in what condition is the ground",6)
screen input 7 35 15 8 10 g_cond
validate(g_cond)
g_cond=Proper($result)
screen clear box 7 30 8 50 0 0 no-border
screen shortrestore $screen
screen print 7 35 15 8 g_cond


scroll("Have any restrictions been placed on the piling (y or n) ?",6)
screen input 7 39 15 8 1 ans mask "[yYnN]"
if ans=="n"
     screen print 7 39 15 8 "N"
     milli-wait 500
     jump no_res
else
     screen print 7 39 15 8 "Y"
     milli-wait 500
end if
screen shortrestore $screen
$limit="***"
'          ***************************    VIBRATION LIMITATIONS

limit()


label no_res
scroll("Have you a prefered hammer (y or n) ? ",6)
screen input 7 39 15 8 1 ans mask "[yYnN]"
if ans=="n"
     screen print 7 39 15 8 "N"
     milli-wait 500
     jump end_input
else
     screen print 7 39 15 8 "Y"
     milli-wait 500
     ch_ham()
     if ans=6
          jump end_input
     end if
end if

label end_input
scroll("Data now being processed ...   Please Wait ",6)

'          ***************      engine starts here

```

```
if p_type=="bearing"
     Energy_req_drp=value(BSP_mod)*(value($mass)*value(depth)/0.8)*9.81/1000
     Energy_req_dsl=Energy_req_drp*0.8/0.6

     $temp_2=str(v[2*$ind-1,value(g_cond)+2])
     if $temp_2=="dense" or $temp_2=="firm"
          Energy_req_drp=Energy_req_drp*1.1
          Energy_req_dsl=Energy_req_dsl*1.1
     end if

     if value(depth)>=20
          Energy_req_drp=Energy_req_drp*1.1
          Energy_req_dsl=Energy_req_dsl*1.1
     end if
     case
          when(Energy_req_drp <= 20)
               Air="BSP 500N"
               Energy_req_air=1.6
          when(Energy_req_drp <= 30)
               Air="BSP 600N"
               Energy_req_air=4.1
          when(Energy_req_drp <= 45)
               Air="BSP 700N"
               Energy_req_air=6.4
          when(Energy_req_drp <= 70)
               Air="BSP 900"
               Energy_req_air=11.9
          when(Energy_req_drp <= 110)
               Air="BSP 1000"
               Energy_req_air=17.8
          otherwise
               Air="BSP 1100"
               Energy_req_air=26.1
     end case
     jump bbb
end if


'         **********          Sheet hammer selection


data goto view "s_e.vw"
data browse off
data goto record record-number 1
data find "[Pile Section]" equal str(section) options "f"
data find "[Single or Double]" equal str(Sheet_2) options "i"
data find "[Pile_Length]" equal str(depth) options "i"
data find "[Soil_Type]" equal str(g_cond) options "i"
Energy_req_dsl=Value([Diesel])
Energy_req_drp=Value([Drop])
if $sec=10
     Energy_req_dsl=Energy_req_dsl*0.9
     Energy_req_drp=Energy_req_drp*0.9
elseif $sec=12
     Energy_req_dsl=Energy_req_dsl*1.1
     Energy_req_drp=Energy_req_drp*1.1
```

```
end if
Energy_req_air=str([Air])
Air="BSP "|Energy_req_air

label bbb

data goto view "hammers.vw"
data browse off

'           ****** Places hammers in correct order

order change index "S_mod"
data goto record record-number 1
data find "[Type]" equal "Diesel" options "i"
data find "[Energy]" Greater-Than str(Energy_req_dsl) options "i"

Diesel=[Manu]&[Model]
$rating_di=value([Energy]/Energy_req_dsl)


data find "[Type]" equal "Drop" options "i"
data find "[Energy]" Greater-Than str(Energy_req_drp) options "i"


Drop=[Manu]&[Model]
$rating_dr=value([Energy]/Energy_req_drp)


if p_type=="sheet"
     data goto record first
     data find "[Type]" partial "Air" options "i"
     data find "[Model]" Partial str(Energy_req_air) options "i"
     Energy_req_air=[Energy]
end if


'           ***********   calculate vibro's


Energy_req_vib=value(g_cond)*$dd

if $sec=10
     Energy_req_vib=Energy_req_vib*0.9
elseif $sec=12
     Energy_req_vib=Energy_req_vib*1.1
end if

order change index "vibrator"
data find "[Type]" partial "Vibro" options "i"
data find "[CF]" Greater-Than str(Energy_req_vib) options "i"
$rating_vi=value([CF]/Energy_req_vib)
Vibro=[Manu]&[Model]
Energy_req_vib=[Energy]

'           **********   goto view output screen

v_screen()
```

```

wait 100
label retry
blanker()

screen print 4 10 15 3 "Please choose an option from the list below"
screen print 8 10 15 3 "1. Run a new query through expert system"
screen print 10 10 15 3 "2. Re-Run present query, changing one or more parameters"
screen print 12 10 15 3 "3. Re-Run present query, changing hammer selected only"
screen print 15 10 15 3 "9. Leave expert system"
screen print 18 10 15 3 "Enter choice here -"
screen input 18 30 15 3 1 $choice mask "[1239]"

if value($choice)=1
     clear global
     jump start
elseif value($choice)=3
     blanker()
     $pref_en=""
     BSP_mod=1
     stop_it=""
     ch_ham()
     jump end_input
elseif value($choice)=9
     clear global
     stop
else
     label changling
     beep 2
     blanker()

     screen print 4 2 15 3 "1. Pile Type         - "|p_type
     screen print 4 45 15 3 "2. Pile Section    - "|str(section)
     screen print 5 2 15 3 "3. Pile Mass         - "|str($mass)
     screen print 5 45 15 3 "4. Single or Pairs - "|str(Sheet_2)
     screen print 6 2 15 3 "6. Ground Type       - "|str(g_type)
     screen print 6 45 15 3 "7. Condition        - "|str(v[2*$ind-1,value(g_cond)+2])
     screen print 8 2 15 3 "8. Alter velocity restrictions"
     screen print 8 45 15 3 "9. Alter hammer type"
     screen print 9 2 15 3 "0. Exit"
     screen print 18 10 15 3 "Enter choice here - "
     screen input 18 30 15 3 1 ans1 mask "[0123456789]"
     case(value(ans1))
          when 1
               screen print 22 20 15 3 "                                                  "
               screen print 22 20 15 3 "Please enter new pile type - "
               screen input 22 49 15 3 20 p_type
               screen print 22 20 15 3 "                                                  "
               $ind=1
               validate(p_type)
               p_type=Proper($result)
               s_or_p()
```

```
          when 2
               screen print 22 20 15 3 "           "
               screen print 22 20 15 3 "Please enter new pile section - "
               screen input 22 49 15 3 20 section
               screen print 22 20 15 3 "           "
               validate(section)
               if p_type=="bearing"
                    section=str(v[2*$ind-1,Value($result)+2])
                    screen print 22 20 15 3 "           "
                    screen print 22 20 15 3 "What is the unit mass of the bearing pile ?"
                    screen input 22 38 15 8 3 ans
                    screen print 22 20 15 3 "           "
                    $ind=$ind+value($result)
                    validate(ans)
                    $mass=value($result)
                    section=proper(section|"*"|str($mass))
               else
                    $mass=""
               end if
               section=$result
          when 6
               screen print 22 20 15 3 "           "
               screen print 22 20 15 3 "Please enter new ground type - "
               screen input 22 49 15 3 20 g_type
               validate(g_type)
               screen print 22 20 15 3 "           "
               g_type=Proper($result)
               if g_type="Granular"
                    $ind=11
               else
                    $ind=10
               end if
          when 7
               screen print 22 20 15 3 "           "
               screen print 22 20 15 3 "Please enter new ground condition - "
               screen input 22 59 15 3 20 g_type
               validate(g_cond)
               screen print 22 20 15 3 "           "
               g_cond=Proper($result)
          when 0
               beep 2
               jump retry
     end case
     screen clear box 12 10 21 62 15 3 no-border
     screen print 22 20 15 3 "Do you want to change another [y or n] ?"
     screen input 22 62 15 3 1 ans1 mask "[yYnN]"
     if ans1=="y"
```

```
            checks()
            jump changling
        end if
end if

wait 100

'    ******          ******          ******          END MAIN    *************
*****

end main

function scroll(txt,row)
local i
screen clear box 4 11 10 69 0 0
for i = 1 to len(txt)
        screen print row (40-len(txt)/2+i) 15 0 chr(txt[i])
        milli-wait 10
end for
end function

function validate(txt)
local i, $temp
$flag=""
screen clear box 9 54 9 69 15 3 no-border
screen print 9 60 15 0 "Verifing"
for i=3 to value(v[(2*$ind)-1,2])+2
        if txt==str(v[(2*$ind)-1,i])
                txt=Proper(v[2*$ind,i])
                $flag="*"
                if $ind=2
                        $sec=i
                end if
        end if
end for

if txt=="quit"
        beep 5
        stop
end if
```

```
if not ($flag="*")
     beep 2
     help_ver()
     screen clear box 9 54 10 69 15 3 no-border
     return
end if
screen print 9 60 15 0 "Verified"
$result=txt
return($result)
end function
function verify_load()
local $trans, i, $sp, cnt1, cnt2, wrd_cnt
fopen "shell.dat" as 1
for i=1 to 24
     wrd_cnt=1
     fread 1 into $trans
     $trans=$trans|" "
     $sp=" "
     cnt1=0
     label starting
     cnt2=find($sp,$trans,cnt1)
     v[i,value(wrd_cnt)]=@mid($trans,cnt1,(cnt2-cnt1))
     wrd_cnt=wrd_cnt+1
     cnt1=cnt2+1
     if cnt2=len($trans)-1
          continue for
     end if
     jump starting
end for
fclose 1
fopen "trends.dat" as 1
for i=1 to 16
     fread 1 into $trans
     tr[i,1]=value(left($trans,4))
     tr[i,2]=value(right($trans,4))
end for
fclose 1
end function
```

```
function screen_pop()
screen clear box 12 11 19 41 15 0 no-border
screen clear box 13 10 20 40 15 1 no-border
screen print 14 12 15 1 "1. Services"
screen print 15 12 15 1 "2. Manufacturing facility"
screen print 16 12 15 1 "3. Residential Housing"
screen print 17 12 15 1 "4. Historical Structure"

end function

function help_ver()
local i,j,k

screen clear box 9 54 9 69 15 3 no-border
screen clear box 12 11 20 62 15 0 no-border
screen clear box 13 10 21 61 15 1 no-border
screen print 13 11 15 1 format "m26" "Allowable responses are :-"
k=0
bottom=value(v[(2*$ind)-1,2])
for i=3 to bottom+2
     if i=11 or i=19 or i=27
          j=j+15
          k=1
     else
          k=k+1
     end if
     screen print 13+k 11+j 15 1 str(v[(2*$ind)-1,i])
end for
$result=menu(10)
if $ind=2
     $sec=value(2+$result)
end if
$result=str(v[2*$ind,2+$result])
return($result)
end function

function menu($y)
local i, $x, offset
     i=1
     screen print 13+i $y 15 1 chr(26)
     label go_again
     $x=inchar
          if not($x=keyvalue("Up") or $x=keyvalue("Down") or $x=keyvalue("Cr"))
               jump go_again
          elseif $x=Keyvalue("Up")
               screen print int(13+i-offset*1.1) int($y+offset*2.2) 1 1 "  "
```

```
                    i=i-1
                    if i<1
                         i=1
                    end if
                    if i=8 and offset=7
                         offset=0
                    elseif i=16 and offset=14
                         offset=7
                    end if
                    screen print int(13+i-offset*1.1) int($y+offset*2.2) 15 1 chr(26)
                    jump go_again
               elseif $x=Keyvalue("Down")
                    screen print int(13+i-offset*1.1) int($y+offset*2.2) 1 1 "  "
                    i=i+1
                    if i=value(bottom)+1
                         i=i-1
                    end if
                    if i=9 and offset=0
                         offset=7
                    elseif i=17 and offset=7
                         offset=14
                    end if
                    screen print int(13+i-offset*1.1) int($y+offset*2.2) 15 1 chr(26)
                    jump go_again
               elseif $x=Keyvalue("Cr")
               end if
               return (i)
end function



function ch_ham()
     local $temp, i, offset, $wide, $$pref
     data goto view "hammers.vw"
     order change index "why"
     screen clear box 12 11 20 32 15 0 no-border
     screen clear box 13 10 21 30 15 1 no-border
     screen print 13 12 15 1 format "m20" "Available Hammers"
     screen print 14 12 15 1 format "l20" "Drop hammer"
     screen print 15 12 15 1 format "l20" "Diesel hammer"
     screen print 16 12 15 1 format "l20" "Air hammer"
     screen print 17 12 15 1 format "l20" "Vibrodriver"
     screen print 18 12 15 1 format "l20" "Quit"
     scroll("Use"&chr(24)&"and"&chr(25)&"keys to choose hammer type, then press enter",6)
     bottom=5
     ans=value(menu(10))
     if ans=5
          return
     end if
     screen clear box 12 1 25 50 15 3 no-border
     data goto record first
     data find [Ident] equal str(ans) options ""
     $temp=record
```

```
     scroll("Please enter the hammer manufacturer ",6)
     while [Ident]=value(ans)
          if value([Band])>0
               i=i+1
               beep 1
               screen print 13+i 12 15 3 format "120" " "|str([Manu])
          end if
          if record=records
               screen print 14+i 12 15 1 format "120" "  "
               exit while
          end if
          data goto record next
     end while
     bottom=Value(i)
     ans=menu(11)
     screen shortrestore $screen
     data goto record record-number $temp
     data find [Band] equal str(ans) options "i"
     $temp=value(record)
     bottom=value([Pref])
     if bottom>9
          $wide=15
          $$pref=10
     else
          $$pref=value([Pref])
     end if
     screen clear box 12 9 11+value($$pref+1) 32+$wide 15 0 no-border
     screen clear box 13 8 12+value($$pref+1) 31+$wide 15 1 no-border
     for i=1 to value(bottom)
          if i=9
               offset=10
          end if
          screen print (13+i-offset*.8) (13+offset*1.5) 15 1 str([Manu])&str([Model])
          data goto record next
     end for
     scroll("Use"&chr(24)&"and"&chr(25)&"keys to choose hammer, then press enter",6)
     i=menu(11)
     scroll("Allocating hammer selection ... ",6)
     data goto record record-number ($temp+i-1)
     if [Type]=="drop" and [Manu]="BSP"
          scroll("Operate Hammer at 0.4m, 0.8m 1.0m or 1.2m stroke ?",6)
          screen input 7 39 15 8 3 BSP_mod mask "[01].[0248]"
     end if
     $pref_hammer=[Manu]&[Model]
     $pref_en=[Energy]*value(BSP_mod)
     $type=[Type]
     screen shortrestore $screen

end function




'               ********       Bodge City

```

```
function v_screen()
local j,vvv,$mark,i, v_comm
screen clear 15 1 no-border
screen print 21 1 15 1 "
                              "
screen print 22 1 15 1 "
                              "
screen print 23 1 15 1 "
                              "
screen print 24 1 15 1 "
                              "
screen print 25 1 15 1 "
                              "
v_comm=""

checks()
'          ******************************************
'          Prepares for prefered hammer
'          ******************************************


if value($pref_en)>0
     case($type)
          when "Diesel"
               $rating_di=value($pref_en/Energy_req_dsl)
               Energy_req_dsl=value($pref_en)
               Diesel="["|$pref_hammer|"]"
          when "Drop"
               $rating_dr=value($pref_en/Energy_req_drp)
               Energy_req_drp=value($pref_en)
               Drop="["|$pref_hammer|"]"
          when "Air"
               Energy_req_air=value($pref_en)
               Air="["|$pref_hammer|"]"
          when "Vibrodriver"
               $rating_vi=value($pref_en/Energy_req_vib)
               Energy_req_vib=value($pref_en)
               Vibro="["|$pref_hammer|"]"
     end case
end if

'          ******************************************
'          Sets default values of v_lim
'          ******************************************

if not($limit="***")
     beep 2
     v_lim=10
elseif $limit="***"
     v_dis=Value(v_dis)
     v_lim=Value(v_lim)
     v_comm=" at "|str(v_dis)|" m."
end if
```

```
'          ******************************************
'          Draws screen and utilises a few bodges due to size pressures
'          ******************************************

screen print 1 23 15 1 format "m34" "Predictive Ground Vibration System"
screen print 1 2 15 1 str(time)
screen print 3 2 15 1 "Pile Type                  - "|str(p_type)
screen print 3 45 15 1 "Pile Section  - "|str(section)&$unit
screen print 4 2 15 1 "Maximum depth of piling   - "|depth|"m"
screen print 5 2 15 1 "Ground Type                - "|str(g_type)
screen print 5 45 15 1 "Ground Cond.  - "|str(v[2*$ind-1,value(g_cond)+2])
screen print 7 2 15 1 "Comments            - "|Sheet_2|vib_comm
screen print 8 2 15 1 "                    - "|str(BSP_mod)
screen print 10 1 15 1 " Dist (m)      Diesel              Air              Drop            Vibro"
screen draw box 9 1 11 78 15 1
screen draw box 9 1 22 10 15 1
screen draw box 9 1 22 27 15 1
screen draw box 9 1 22 44 15 1
screen draw box 9 1 22 61 15 1
screen draw box 9 1 22 78 15 1
screen print 25 2 15 1 format "m78" "Velocity limit - "|Str(v_lim)|" mm/sec"|str(v_comm)

if g_type=="Granular"
    $mark=1
else
    $mark=3
    screen print 10 62 4 1 "***"
    screen print 10 75 4 1 "***"
end if

if p_type=="Bearing"
    $mark=$mark+1
end if


'          ******************************************
'          $mark locates the correct equations in trend array.
'          vv[] is filled with the relevent data
'          ******************************************

for i = 1 to 10
    vv[i,1]=2*i
    screen print 11+i 2 15 1 format "0m8" str(vv[i,1])
    vv[i,2]=tr[$mark,2]*(((Energy_req_dsl)^0.5)/vv[i,1])^tr[$mark,1]
    vv[i,3]=tr[4+$mark,2]*(value(Energy_req_air)^0.5/vv[i,1])^tr[4+$mark,1]
    vv[i,4]=tr[8+$mark,2]*((Energy_req_drp)^0.5/vv[i,1])^tr[8+$mark,1]
    vv[i,5]=tr[12+$mark,2]*((Energy_req_vib)^0.5/vv[i,1])^tr[12+$mark,1]
    milli-wait 100
    if stop_it="xxx"
        vv[i,3]="n/a"
        Air="n/a"
    end if
    for j=1 to 4
```

```
          screen print 11+i (-1+j*17) 15 1 format "1m6" str(vv[i,j+1])
     end for
end for

screen print 23 3 15 1 "Hammer"
screen print 24 3 15 1 "Rating"

screen print 23 11 15 1 format "m16" Diesel
screen print 23 28 15 1 format "m16" str(Air)
screen print 23 45 15 1 format "m16" Drop
screen print 23 62 15 1 format "m16" Vibro

screen print 24 11 15 1 format "2m16" str($rating_di)
screen print 24 45 15 1 format "2m16" str($rating_dr)
screen print 24 62 15 1 format "2m16" str($rating_vi)


'         *******************************************
'         Calculates the vibration limitations
'         *******************************************

if v_dis>0
     vvv=int(v_dis/2)
     screen print 11+vvv 2 0 14 format "0m8" str(vv[vvv,1])
     screen print 11+vvv 2 0 14 chr(26)
     screen print 11+vvv 9 0 14 chr(27)
end if


for j = 2 to 5
     for i = 1 to 10
          if vv[i,j]>=value(v_lim)
               screen print 11+i (17*(j-1)-6) 15 4 format "1m16" str(vv[i,j])
          end if
          if vv[i,j]>=0 and vv[i,j]<value(v_lim)
               screen print 11+i (17*(j-1)-6) 15 9 format "1m16" str(vv[i,j])
          end if
          if g_type=="cohesive"
               screen print 11+i 62 0 15 format "1m16" str(vv[i,5])
          end if
     end for
end for


end function

'              ********************    vibration limitations   ***********


function limit()
local ans1
scroll("Has a vibration limit been fixed (y or n) ?",6)
screen input 7 39 15 8 1 ans mask "[yYnNq]"
if ans=="y"
```

```
        screen print 7 39 15 8 "Y"
        milli-wait 500
        scroll("And what is that vibration limit [mm/sec] ?",6)
        screen input 7 38 15 8 3 v_lim
        scroll("At what minimum distance from piling [m] ?",6)
        screen input 7 38 15 8 3 v_dis
        return
else
        screen print 7 39 15 8 "N"
        milli-wait 500
end if

scroll("What has placed a restriction on the piling ?",6)
screen_pop()
bottom=4
ans=menu(10)
if value(ans)=1
        scroll("Restriction caused by services ...",6)
        screen clear box 11 11 16 41 15 0 no-border
        screen clear box 12 10 17 40 15 1 no-border
        screen print 12 13 15 1 format "m28" "Are the services :-"
        screen print 14 12 15 1 "1. Overground"
        screen print 15 12 15 1 "2. Underground"
        ans1=menu(10)
        if ans1=1
                v_lim=40
                $res="OverGround Services"
        elseif ans1=2
                v_lim=30
                $res="UnderGround Services"
        else
                screen shortrestore $screen
        end if
elseif value(ans)=2
        scroll("Restriction caused by manufacturing facility ...",6)
        screen clear box 12 11 19 41 15 0 no-border
        screen clear box 13 10 20 40 15 1 no-border
        screen print 13 13 15 1 format "m28" "Type of facility :-"
        screen print 14 12 15 1 "1. Heavy industrial"
        screen print 15 12 15 1 "2. Light industrial"
        screen print 16 12 15 1 "3. Micro-electronics"
        ans1=menu(10)
        if ans1=1
                v_lim=30
                $res="Heavy Industrial Manufacturing Facility"
        elseif ans1=2
                v_lim=25
                $res="Light Industrial Manufacturing Facility"
        elseif ans1=3
                v_lim=5
                $res="Micro-electronics Facility"
        else
                screen shortrestore $screen
        end if
elseif value(ans)=3
        scroll("Restriction caused by residential housing ...",6)
        screen clear box 12 11 19 41 15 0 no-border
```

```
    screen clear box 13 10 20 40 15 1 no-border
    screen print 13 13 15 1 format "m28" "Is the housing in :-"
    screen print 14 12 15 1 "1. Good condition"
    screen print 15 12 15 1 "2. Poor condition"
    ans1=menu(10)
    if ans1=1
        v_lim=10
    elseif ans1=2
        v_lim=5
    else
        screen shortrestore $screen
    end if
elseif value(ans)=4
    scroll("Restriction caused by historical structure ...",6)
    screen clear box 12 11 19 41 15 0 no-border
    screen clear box 13 10 20 40 15 1 no-border
    screen print 13 13 15 1 format "m28" "General condition :-"
    screen print 14 12 15 1 "1. Good condition"
    screen print 15 12 15 1 "2. Poor condition"
    ans1=menu(10)
    if ans1=1
        v_lim=5
        $res="Good condition historical structure"
    elseif ans1=2
        v_lim=3
        $res="Poor condition historical structure"
    else
        screen shortrestore $screen
    end if
end if
screen shortrestore $screen
scroll("And at what distance from the piling [m]?",6)
screen input 7 38 15 8 3 v_dis

return
end function

function blanker()

screen clear 0 3 no-border
screen print 21 1 15 3 "                                                                                "
screen print 22 1 15 3 "                                                                                "
screen print 23 1 15 3 "                                                                                "
screen print 24 1 15 3 "                                                                                "
screen print 25 1 15 3 "                                                                                "
screen print 1 1 14 3 format "m80" "GROUND VIBRATION EXPERT SHELL SYSTEM"

end function


function s_or_p()

```

```
if p_type="Bearing"
     $ind=3
else
     $ind=2
     screen clear box 7 30 8 50 0 0 no-border
     scroll("Are the piles being driven in (p)airs or in (s)ingles?",6)
     screen input 7 39 15 8 1 Sheet_2 mask "[sSpP]"
     if Sheet_2=="s"
          screen print 7 37 15 8 "Singles"
          milli-wait 500
     else
          screen print 7 38 15 8 "Pairs"
          milli-wait 500
     end if
end if

end function



function checks()

'         *******************************************
'         Screen variables for single or pairs
'         *******************************************

if Sheet_2=""
     Sheet_2=null
     comm=null
elseif Sheet_2=="s"
     Sheet_2="Singles."
elseif Sheet_2=="p"
     Sheet_2="Pairs."
end if


'         *******************************************
'         sets up so section shows correct on screen
'         *******************************************
if p_type=="sheet"
     section=str(v[3,$sec])
else
     $unit="kg/m"
end if

'         *******************************************
'         corrects depth for range for sheet piles
'         *******************************************

if depth=="l"
     depth="<= 12"|" ("|str($dd)|")"
elseif depth=="g"
     depth="> 12"|" ("|str($dd)|")"
end if

'         *******************************************
'         Sets up modifier and comments for BSP hammer
```

```
'          ******************************************

if value(BSP_mod)=1
     BSP_mod=null
else
     BSP_mod="BSP Drop height set at"&BSP_mod |"m."
end if

'          ******************************************
'          Checks to see if dodgy air/cohesive/bearing and blanks
'          ******************************************

if p_type=="bearing" and g_type=="cohesive"
     stop_it="xxx"
end if

'          ******************************************
'          Warns user about cohesive soils and vibro's
'          ******************************************

if g_type=="cohesive"
     vib_comm=" ** Vibrodivers not recommended for cohesive soils **"
end if


end function
```

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