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Whole-body vibration on construction, mining and quarrying machines

Evaluation of emission and estimated exposure levels

Prepared by **Silsoe Research Institute**
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A J Scarlett
Silsoe Research Institute
Wrest Park
Silsoe
Bedford MK45 4HS

R M Stayner
RMS Vibration Test Laboratory
26 Coder Road
Ludlow Business Park
Ludlow
Shropshire SY8 1XE

A study was conducted to quantify whole-body Vibration (WBV) emission and likely operator daily exposure levels associated with the normal operation of 13 different types of machine used in the construction, earthmoving, quarrying and mining industries. WBV measurements were made on 16 working machines, encompassing (if possible) a half-day (3-4 hours) of commercial activity, to provide representative samples of WBV time-histories. Frequency analysis of the vibration data and direct observation provided information on the potential for reducing operator WBV exposure in each instance, by appropriate selection and use of suspended seats.

Machine WBV emission and operator daily exposure levels fell into three broad categories:

- Low WBV exposure levels, not exceeding the Exposure Action Value (EAV) in a typical working day;
- Moderate WBV exposure levels, above the EAV, but not approaching the Exposure Limit Value (ELV) in a typical working day;
- Higher levels of WBV, potentially approaching the ELV in a typical working day.

Suspended seats, if appropriately selected and properly maintained, may provide useful reduction of vertical (Z-axis) whole-body vibration on machines such as Fork Lift Trucks, Site Dumpers and Bulldozers.

The most important factors in controlling/reducing operator exposure to WBV are likely to be adequate information and appropriate training in 'Best Practice'. Maintenance of haul roads and/or other operating surfaces can help to reduce machine WBV emission/operator exposure levels, but only if vehicle travel speeds are also controlled. Care is required in measuring operator WBV exposure levels in instances when the operator spends a proportion of the measurement period absent from the vehicle seat.

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EXECUTIVE SUMMARY

The overall objective of this investigation was to determine currently achievable Whole-Body Vibration (WBV) emission and likely operator daily exposure levels associated with 13 different types of machine used in the construction, earthmoving, quarrying and mining industries. WBV measurements were made on 16 working machines, selected in conjunction with the relevant industrial trade association, encompassing (if possible) a half-day (3–4 hours) of commercial activity, in order to provide representative samples of WBV time-histories. Frequency analysis of the vibration data and direct observation provided information on the potential for reducing operator WBV exposure by appropriate selection and use of suspended seats.

WBV exposure analyses have been made on one or two examples of each of 13 different types of machine used in the construction, earthmoving, quarrying and mining industries.

Of these, the following were found to expose operators to low levels of WBV, not exceeding the Exposure Action Value (EAV) in a typical working day:-

- Excavating with either a Backhoe Loader or a 1.5-tonne 360° Excavator (mini-digger);
- Compacting tarmac using a 10-tonne or 4-tonne Twin-Drum Articulated Roller, with or without roller vibration engaged;
- Transport using a 32-tonne 8-wheeled Truck (tipper lorry), including short distances off the highway.

An 80-tonne Rigid Dump Truck in an open-cast mine was also found to generate low levels of WBV emissions, but the operating conditions may have been relatively benign, and higher emission levels might be expected in more common operating conditions. These would probably cause the EAV to be exceeded during a typical working day, but not the Exposure Limit Value (ELV).

Other machines or operations that were found to subject the operator to daily WBV exposure above the EAV, but not approaching the ELV (over a typical working day) were:-

- Backhoe Loader in transport mode;
- 3-tonne Site Dumper transferring soil between an excavator and a local spoil heap;
- Face Shovel loading dump trucks in a rock quarry;
- Fork Lift Trucks used in a concrete products plant or at a colliery surface;
- Skidsteer Loader used for general duties on a domestic building site.

18 and 24-tonne Articulated Loading Shovels would fall into the above category, or might expose operators to levels approaching the ELV, depending on how the machines are used (operating technique and surface condition).

Machines found to expose operators to higher levels of WBV, potentially approaching the ELV in a typical working day included:-

- 3-tonne Site Dumper transporting soil over longer distance of moderate roadway;
- 25-tonne Articulated Dump Truck;
- Wheeled (Motor) Scraper.

A Bulldozer also fell into this last category, but only because its suspension seat had been allowed to fall into a very bad state. With a properly maintained seat, it would probably have come within the second of the above groups.

Suspended seats, if appropriately selected and properly maintained, may provide useful reduction of vertical (Z-axis) whole-body vibration on machines such as Fork Lift Trucks, Site Dumpers and Bulldozers.

The most important factors in controlling / reducing operator exposure to WBV are likely to be adequate information and appropriate training in 'Best Practice'. Maintenance of haul roads and/or other operating surfaces can help reduce machine WBV emission / operator exposure levels, but only if vehicle travel speeds are also controlled.

Care is required in measuring operator WBV exposure levels in instances when the operator does not spend the entire measurement period (or at least 95% of it) on the vehicle seat.

1. INTRODUCTION AND INVESTIGATION OBJECTIVES

During the course of normal daily operation, drivers of off-road vehicles may well be exposed to high levels of whole-body vibration (WBV), causing discomfort and increased risk of lower-back pain. The main sources of WBV are considered to be the seats of industrial and agricultural vehicles, and the platforms of heavy machinery.

Recent European Parliament legislation (EU Physical Agents (Vibration) Directive, 2002) prescribes minimum standards for health & safety of workers exposed to either Hand-Arm or Whole-Body vibration. In addition to requiring employers to minimise worker vibration exposure wherever practicable, specific daily vibration exposure levels (Exposure Action Value (EAV) & Exposure Limit Value (ELV)) are defined. If a worker is liable to be exposed to vibration, an assessment of the likely daily vibration exposure is required. Should the exposure level exceed the EAV, a range of measures must be employed to reduce exposure and minimise risks. If the ELV is exceeded, immediate action must be taken to reduce vibration exposure below the ELV and measures be implemented to prevent it being exceeded again.

As vibration exposure is a function of vibration 'magnitude' and exposure 'duration', the operating duration of certain machine types, which generate high levels of vibration, may possibly be limited. Also, particularly with regard to WBV, it should be stressed that the Exposure Limit Value (ELV) stated by the Directive should not be considered a 'safe' level of vibration exposure in the workplace, but rather as a high, undesirable level of vibration exposure (and a legal threshold) to be avoided at all costs. It is for this reason the Directive requires action to be taken, so far as is reasonably practicable, to minimise vibration exposure once levels exceed the Exposure Action Value (EAV).

Following the implementation of this legislation in the UK in July 2005 (Control of Vibration at Work Regulations, 2005), employers will be required to perform "a suitable and sufficient assessment of risk", including estimation of worker daily vibration exposure level, to determine whether the EAV or ELV are likely to be exceeded during normal working. Whilst this could be based upon actual exposure measurement in the workplace, an adequate assessment may be possible by use of vibration emission / exposure information for the generic machine type / activity in question. This could possibly be sourced from manufacturer's data or, more probably, from published research data, made available by the Health & Safety Executive (HSE) and other similar bodies. It was therefore of considerable importance that an adequate, robust database of WBV (emission and) daily exposure data was generated to encompass as wide a range of machines and operations as deemed necessary by the Executive, prior to the introduction of the legislation.

In the period leading up to the implementation of the Control of Vibration at Work Regulations (TBA, 2005), various industries have been concerned to know whether or to what extent these regulations are likely to affect their workers, and hence to affect their operations. Amongst those concerned about whole-body vibration (WBV) was the construction industry, which collaborated with the Health & Safety Executive through certain of its trade associations (the Federation of Master Builders and the Quarry Products Association). For reasons of cost and time, it was agreed that, within the scope of this investigation, whole-body vibration should be recorded on only one example each of a range of machines. That range was selected at meetings between the Trade Associations, the HSE and the selected contractors, between whom the work of data recording and analysis was shared. This document reports only the work performed by Silsoe Research Institute, in collaboration with RMS Vibration Test Laboratory.

The investigation was to target a number of on-site examples of specific machines (as they perform their normal operations), as encountered in the construction, mining and quarrying industries. For each on-site example the objective was to determine Whole-Body Vibration (WBV) emission and operator exposure levels associated with machine operation, establishing in each instance:-

- The circumstances which would lead to WBV exposures in excess of the Exposure Action Value (EAV) or the Exposure Limit Value (ELV);
- The parameters that most affect WBV exposure levels;
- WBV datasets from which generic WBV exposure assessments may be made.

In addition to these precise objectives, it was important to determine whether there are any types of machine or operation within these industries that are likely to be associated with levels of WBV high enough to be of concern, and to indicate any machines or operations for which WBV exposure is likely to be of minor importance. Further to this, the study was to highlight factors that contributed significantly to any high levels of vibration that were found, leading to suggestions for where improvements could be achieved.

2. WHOLE-BODY VIBRATION (WBV) MEASUREMENT AND ANALYSIS

2.1 MEASURED PARAMETERS & TRANSDUCERS

Acceleration levels were measured simultaneously in three mutually-perpendicular directions (X - longitudinal, Y - transverse, Z - vertical) at two locations on each target machine, namely upon the surface of the operator's seat and on the cab floor beneath the seat. In addition, an operator presence switch was fitted upon the seat surface, to provide an indication of operator absence from the cab during the measurement period. For each target machine, one of three sets of transducers was used (see below). The particular transducer configuration utilised upon each machine is identified in the "Operational Details" sub-section of each machine-specific Appendix (see Appendix 1). More specifically they were as follows:-

2.1.1 Transducer set 1

Tri-axial vibration present on the cab floor, close to the seat mounting point was measured using an array of three mutually-perpendicular piezo-resistive accelerometers with integral signal conditioning *(IC Sensors type 3140-005),* housed within a rigid plastic enclosure (see Figure 2.1). Vibration on the driver's seat was measured by placing a semi-rigid mounting disc, incorporating a tri-axial 100mV/g ICP accelerometer *(PCB model 356B40)*, on the seat cushion, approximately between the driver's ischial tuberosities (vertically below the Seat Index Point). The operator presence switch, which was actually an array of 4 switches connected in parallel, was fitted immediately over the seat accelerometer pad. The seat pad was attached to the cushion using a combination of double-sided tape and "Gaffa" tape, and the operator presence switch by means of "Gaffa" tape alone. The whole was covered with a thin polythene sheet for protection (see Figure 2.2).

2.1.2 Transducer set 2

In some machines there was not enough space for the piezo-resistive floor accelerometer box. In these cases, the tri-axial accelerometer from the PCB seat pad *(PCB model 356B40)* was attached to the machine by means of a magnetic clamp (see Figure 2.3), and a pad containing a tri-axial piezoelectric accelerometer *(B&K model 4322)* substituted on the seat surface.

2.1.3 Transducer set 3

Independently of the above two transducer configurations, measurements were made upon certain target machines with two tri-axial 100mV/g ICP accelerometers *(PCB model 356B40)*. One of these was attached to the machine floor by a magnetic clamp as for transducer set 2 (see Figure 2.3), while the other was fitted into a pad that was attached to the seat cushion (as in Figure 2.2). As in both of the above arrangements, a switch array was used to detect operator presence.

Figure 2.1 ‘Floor’ tri-axial accelerometer configuration (Transducer set 1)

Figure 2.2 ‘Seat’ accelerometer configuration incorporating operator presence switch

Figure 2.3 Tri-axial 'Floor' accelerometer installation using magnetic mounting

Figure 2.4 Data acquisition pack installations on machines: within cab (left) and 'alfresco' (right)

2.2 DATA ACQUISITION & RECORDING

Two similar sets of equipment were used for data acquisition and recording. Signals from each tri-axial accelerometer were passed through Human Vibration Meters *(Larson Davis type HVM 100)* to a miniature, 8-channel digital data recorder, the latter using PCMCIA-sized flash data storage cards (*TEAC model DR-C2 PC-card recorder with 128Mb data card).* Both sets contained signal conditioning for the operator presence switch array, which was connected to the 7th channel of the digital data recorder, together with supplementary batteries to extend the life of the internal batteries of the Human Vibration Meters and of the data recorder.

The data acquisition pack used with transducer sets 1 and 2 (see Section 2.1) also included signal conditioning for the piezo-resistive floor accelerometers. This arrangement produced a compact and rugged system that was suitable for attachment either inside or outside the cabs of the machines to be investigated (see Figure 2.4). The digitising rates of the PC card recorders were set to 500 Hz.

The Human Vibration Meters (HVMs) provided the equivalent of anti-aliasing filters for the PC card recorders and also an alternative data acquisition system for acceleration time histories, but not for the operator presence signal. For data acquisition purposes, the memories of the HVMs were set to hold r.m.s. averages of the weighted acceleration signals, together with the peak acceleration, for each minute of work, and Vibration Dose Values (VDV) for each 15-minute period. These HVM memories were downloaded to a PC for post-processing, as described below, while the digitised recording provided a history of operator presence as well as a record of the vibration data for more detailed analysis.

The time required for both fitting and removal of the transducers and data acquisition pack was about 30 minutes. Therefore, to minimise disruption of the commercial operations for which the machines were being used, the fitting and removal were performed during normal work breaks if possible. This led to data recording times that were generally between 3 and 4 hours, where site operations permitted such durations.

2.3 DATA ANALYSIS

The first stage in data analysis involved calculations from the acceleration - time histories acquired by the HVMs. These histories were stored as frequency-weighted values, whether r.m.s. or VDV. However, although the 1.4 multiplying factor had been used in generating the stored RSS values, it was not applied to the individual horizontal axes values as stored. Consequently, after downloading to a PC as text files, the HVM-stored data was imported into spreadsheets for calculation of cumulative r.m.s. values (Aeq) and Vibration Dose Values (with 1.4 multiplier where necessary) for the measurement period in question. These spreadsheets were also used to calculate, for each 'seat' acceleration record, estimates of VDV's for an 8-hour exposure period and of the operating time to reach the Exposure Action and Limit Values (EAV & ELV), as defined in the Physical Agents (Vibration) Directive. They were also used for presentation of acceleration history curves.

The data from the PC card recorders were used to refine and extend the analyses in several ways, using *HvLab* software (see below).

The first stage of *HvLab* analysis involved using the operator presence signal to set to zero the acceleration records for those times when the operator left the seat, and subsequently to re-calculate the cumulative r.m.s. (A_{eq}) values and the VDVs. This was particularly important for machines such as fork-lift trucks, the use of which involved the operator dismounting frequently, and for as much as 50% of the time (see Section 4.2). The revised data files were then used to calculate frequency power spectra and the vertical transfer function of the seat, complete with the associated coherence function.

In one case, which involved a considerable amount of "waiting" time, but where the operator did not leave his seat, calculation of the amplitude distribution of the seat accelerations enabled estimates to be made of the proportion of waiting time to travelling time.

3. TARGET MACHINES AND APPLICATIONS

This investigation was originally commissioned by the Health and Safety Executive to determine WBV emission and operator exposure levels upon 10 different types of machine used in the construction, earthmoving and quarrying industries: specifically those deemed likely to exhibit high WBV emission / operator exposure levels and for which WBV information was not then readily available.

During the course of the investigation the original target list was expanded to 12 machine types: subsequently three extra machines were included at the request of the mining industry, and circumstances allowed two vibrating rollers to be tested at the same site. The final 16 machines encompassed by the study are listed in Table 3.1, together with brief descriptions of what they were doing, and of the type of site on which they were being used. In several instances, the recorded operating period involved the machine in question performing more than one distinct activity / operation. Where this was case, the resulting WBV data were analysed separately (see Section 4), and the specific activities are indicated in Table 3.1.

Full details of each machine, the particular operating application(s), and the resulting WBV levels are presented in Appendix 1.

Table 3.1 Machines and activities targeted during investigation

Machine Type / No.	***Machine Activity***	***Location***	***Unladen Mass (t) (Capacity (t))***
1. JCB 4CX Super Backhoe Loader:-	*Trenching / Excavating footings*	Building Site	8.9 (-)
	Loading soil & carrying along farm track	Building Site	
	Road travel	Public Road	
2. 3-tonne Articulated Site Dumper	*Spoil removal from site excavation*	Building Site	mass unknown (3)
	Soil transport along farm track		
3. 25-tonne Articulated Dump Truck	*Soil transport from 360° excavator*	Landfill Site	22 (25)
4. Bulldozer	*Dozing soil*	Landfill Site	18.5 (-)
5. Face Shovel	*Loading dump trucks*	Granite Quarry	225 (~ 25)
	On-site travel		
6. 10-tonne Twin-Drum Articulated Roller	*Compacting tarmac*	Motorway	10 (-)
7. 4-tonne Twin-Drum Articulated Roller	*Finishing tarmac*	Motorway	4 (-)
8. 18-tonne Articulated Loading Shovel	*Handling bulk aggregates*	Asphalt Plant	18 (-)
9. 24-tonne Articulated Loading Shovel	*Loading rail wagons*	*Colliery Stockpile Yard*	24 (-)
	Loading lorries / feeding screening machine		
10. 32-tonne 8-wheeled Truck	*Road transport*	Quarry / Highway	11.5 (20.5)
11. 2.5-tonne Fork Lift Truck	*Product transfer – kiln to store*	Concrete Products Plant	4 (2.5)
12. 6.5-tonne Fork Lift Truck	*Stockyard transfer*	Colliery Yard	9.5 (6.5)
13. 1.5-tonne 360° Excavator	*Excavating house extension footings*	Domestic Property	1.6 (-)
14. 80-tonne Rigid Dump Truck	*Overburden transport (short haul)*	Open Cast Mine	87 (80)
15. Skidsteer Loader	*Site levelling / moving asphalt*	Domestic Property	3.3 (-)
16. Wheeled (Motor) Scraper	*'Cut & Fill' soil movement*	Gas Receiving Plant	44 (36)

4. INVESTIGATION RESULTS

4.1 SUMMARY OF MACHINE WHOLE-BODY VIBRATION LEVELS

As previously discussed in Section 2.1, this investigation undertook to measure WBV time histories upon the target machine (ideally) over a 4 hour / half-shift period of example machine operation, to ensure the acquired vibration data was representative of WBV exposure / machine operation during the working day. The recorded data included:-

- WBV levels measured with respect to time in three orthogonal axes (X, Y & Z), both upon the surface of the operator's seat and the cab floor beneath the seat;
- A record of operator presence upon the seat (i.e. indication of absence from the cab during the measurement period).

In addition to the above, wherever possible the following were observed and recorded during the operating period of each machine:-

- Machine type, make, model, age, condition, particular modifications (e.g. oversize tyres), operator's settings and operator's weight;
- Vehicle seat type, make, model, condition (overall), suspension system condition and setting (if present);
- Site layout and terrain encountered during operating period;
- Mode, duration & pattern of machine operation (including constituent operating cycles), and approximate speed of operation (derived by observation) throughout the period of WBV measurement, to enable subsequent attribution of specific operating patterns and/or activities to given segments of the recorded WBV time histories;
- Key factors deemed likely to affect machine WBV exposure levels, including site condition, operator behaviour / personal operating technique, presence upon machine, and machine condition.

Analysis of acceleration time histories recorded upon the operator's seat and cab floor of the target machines permitted derivation of the following:-

- Frequency and measurement axis-weighted acceleration time histories, processed in accordance with the requirements of ISO 2631-1: 1997 "Effect of Vibration on Health";
- Overall average, frequency-weighted energy-equivalent continuous r.m.s. acceleration (Aeq) for the duration of measurement;
- Vibration Dose Value (VDV) for the duration of measurement;
- Estimated operator daily vibration exposure, presented in 8-hour energy-equivalent continuous, frequency-weighted r.m.s. acceleration (A(8)) and VDV forms;
- Time to reach the EAV and ELV, when specified both in A(8) and VDV forms;
- Estimated vibration dose value for an 8-hour working day;
- r.m.s. and VDV "SEAT" (seat effective amplitude transmissibility) values;
- Acceleration power spectral density (p.s.d.) values for each data channel;
- H1 frequency response spectrum for the operator's seat (in vertical (Z) axis) and associated coherence.

All of the above-mentioned parameters were calculated and reported separately for each machine / activity combination identified in Table 3.1. Comprehensive details of each machine / operational application and resultant WBV data are presented in Appendix 1: a summary overview appears in Tables 4.1 and 4.2 for r.m.s. acceleration and VDV analyses, respectively.

Table 4.1 Machine WBV seat data summary (rms acceleration)

Machine / No. / Activity		*Average rms acceleration (m/s^2)*				*Time to EAV (hr) (A(8))*	*Time to ELV (hr) (A(8))*	*SEAT value*
		X	*Y*	*Z*	*Major axis*			
1. JCB 4CX Super Backhoe Loader:-	*Trenching / Excavating*	0.29	0.24	0.21	X	23.3	>24	-
	'Load & carry'	0.50	0.71	0.37	Y	4.0	21.1	1.12
	Road travel	0.52	0.45	0.47	X	7.3	>24	1.21
2. 3-tonne Articulated Site Dumper	*Spoil removal*	0.42	0.53	0.43	Y	7.2	>24	0.78
	Soil transport	0.83	0.91	0.96	Z	2.2	11.6	1.13
3. 25-tonne Articulated Dump Truck	*Soil transport*	0.78	0.92	0.58	Y	2.3	12.4	0.91
4. Bulldozer	*Dozing*	0.63	0.55	1.45	Z	1.0	5.0	1.16
5. Face Shovel	*Loading trucks*	0.74	0.50	0.61	X	3.6	19.2	0.85
	On-site travel	0.64	0.70	1.04	Z	1.9	9.9	0.93
7. 4-tonne Twin-Drum Articulated Roller	*Finishing tarmac*	0.28	0.38	0.48	Z	8.8	>24	0.86
9. 24-tonne Articulated Loading Shovel	*Loading rail wagons*	0.96	0.75	0.58	X	2.2	11.5	1.16
	Stockpile yard work	0.70	0.67	0.59	X	4.1	21.7	1.26
10. 32-tonne 8-wheeled Truck	*Road transport*	0.16	0.25	0.43	Z	10.6	>24	1.00
13. 1.5-tonne 360° Excavator	*Excavating*	0.42	0.30	0.22	X	11.4	>24	0.92
14. 80-tonne Rigid Dump Truck	*Soil transport*	0.34	0.35	0.37	Z	14.9	>24	1.03
16. Wheeled Scraper	*'Cut & Fill'*	0.96	0.97	0.64	X / Y	2.1	11.2	1.33

NB:- Results for machines Nos. 6, 8, 11,12 & 15 are presented in Table 4.3.

Table 4.2 Machine WBV seat data summary (VDV)

Machine / No. / Activity		*Estimated 8-hour VDV ($m/s^{1.75}$)*				*Time to EAV (hr) (VDV)*	*Time to ELV (hr) (VDV)*	*SEAT value*
		X	*Y*	*Z*	*Major axis*			
1. JCB 4CX Super Backhoe Loader:-	*Trenching / Excavating*	7.2	6.7	9.8	Z	6.1	>24	-
	'Load & carry'	9.5	13.8	7.5	Y	1.5	>24	1.09
	Road travel	9.9	8.1	9.2	X / Z	5.7	>24	1.22
2. 3-tonne Articulated Site Dumper	*Spoil removal*	11.1	9.9	13.0	Z	1.9	>24	1.16
	Soil transport	17.8	19.0	21.4	Z	0.3	7.5	1.22
3. 25-tonne Articulated Dump Truck	*Soil transport*	17.7	20.9	14.2	Y	0.3	8.2	0.81
4. Bulldozer	*Dozing*	15.0	11.4	26.0	Z	0.1	3.4	1.02
5. Face Shovel	*Loading trucks*	17.4	12.3	15.4	X	0.6	17.1	0.67
	On-site travel	12.5	12.7	17.4	Z	0.6	17.0	0.81
7. 4-tonne Twin-drum Articulated Roller	*Finishing tarmac*	7.4	9.3	12.7	Z	2.1	>24	1.06
9. 24-tonne Articulated Loading Shovel	*Loading rail wagons*	23.4	15.8	14.2	X	0.2	5.2	1.19
	Stockpile yard work	16.6	14.2	16.7	X / Z	0.7	20.0	1.35
10. 32-tonne 8-wheeled Truck	*Road transport*	4.9	5.8	9.0	Z	8.2	>24	1.00
13. 1.5-tonne 360° Excavator	*Excavating*	11.3	8.2	11.7	X / Z	2.9	>24	1.58
14. 80-tonne Rigid Dump Truck	*Soil transport*	9.3	10.0	14.8	Z	1.1	>24	1.11
16. Wheeled Scraper	*'Cut & Fill'*	21.9	21.5	15.7	X / Y	0.2	6.7	1.30

NB:- Results for machines Nos. 6, 8, 11,12 & 15 are presented in Table 4.4.

4.2 INFLUENCE OF OPERATOR PRESENCE 'ON-SEAT'

For most of the machine / application examples included in this study, the driver / operator seldom left his seat. However, there were five machine examples (Machine Nos. 6, 8, 11, 12 & 15) when he did (see Tables 4.3 & 4.4), so categorised by the fact that the period spent 'on-seat' was less than 95% of the total operating period. In four of these cases operator absence was a frequent occurrence ('on-seat' period < 90%), but the frequency and duration of the absences was highly dependent upon the activity in question (a time-history of operator seat presence is depicted graphically in the Appendices relating to each of these machines).

A particular case in point is the operation of fork lift trucks (Machine Nos. 11 & 12), which comprises a sequence of short periods of driving interspersed with periods of manual handling, resulting in 'on-seat' values of approx. 50% (see Tables 4.3 & 4.4). The operators of the 18-tonne loading shovel and the 10-tonne roller spent approx. 85 – 90% of their time 'on-seat', the former being out of the cab to undertake other duties at the asphalt plant; the latter (by coincidence) whilst waiting for fresh deliveries of asphalt to the section of motorway carriageway being laid. At the opposite end of the spectrum, the skidsteer loader operator only spent 29% of his time 'on-seat', the remainder being spent assisting his workmates shovel the driveway material into place.

In theory, if a machine operator receives no vibration from any other source whilst 'off-seat', his overall vibration exposure level should not be adversely affected by absence from the machine. However, this situation is not necessarily reflected in the recorded WBV data, as shown by Tables 4.3 and 4.4. If the driver leaves the machine's engine running when he is 'off-seat', some vibration will continue to be recorded. In most instances, this is at a low level and affects the overall average acceleration / vibration values only slightly (e.g. Machine Nos 8, 11 & 15).

However, in other cases, such as the 6.5-tonne fork lift truck at the colliery (Machine No.12) and especially the 10-tonne vibrating roller (Machine No.6), the low frequency vibration generated at engine tick-over and recorded on the seat surface (without the operator's weight being present) is significantly greater than that when the machine is operating normally (see Appendices 1.6 & 1.12). If this had not been eliminated from the data analysis, a WBV magnitude of 1.06 m/s^2 would have been found for the fork lift truck, instead of 0.59 m/s^2 for the time when the driver was on the seat (see Table 4.3). In the case of the 10-tonne vibrating roller, an apparent magnitude of 0.54 m/s^2 was reduced to 0.31 m/s^2 and the largest axis re-designated, by eliminating periods when the driver was off the seat. It is therefore of great importance to record (with accuracy) periods of operator absence, so their effect upon operator WBV exposure level may be taken into consideration (if significant).

Table 4.3 WBV seat data summary (rms acceleration) for machines where driver spent less than 95% of operating period 'on-seat'

Machine / No. / Analysis Period		***Average rms acceleration (m/s^2)***				***Time to EAV (hr) (A(8))***	***Time to ELV (hr) (A(8))***	***SEAT value***
		X	***Y***	***Z***	***Major axis***			
6. 10-tonne Twin-drum Articulated Vibrating Roller	*Entire Operating Period*	0.29	0.38	0.54	Z	6.9	>24	0.96
	Period when Driver is 'On-Seat' (90%)	0.27	0.37	0.31	Y	14.3	>24	0.66
8. 18-tonne Articulated Loading Shovel	*Entire Operating Period*	0.59	0.53	0.38	X	5.7	>24	1.19
	Period when Driver is 'On-Seat' (86%)	0.59	0.53	0.35	X	5.8	>24	1.10
11. 2.5-tonne Fork Lift Truck	*Entire Operating Period*	0.40	0.45	0.58	Z	5.9	>24	0.48
	Period when Driver is 'On-Seat' (52%)	0.39	0.45	0.57	Z	6.2	>24	0.48
12. 6.5-tonne Fork Lift Truck	*Entire Operating Period*	0.30	0.30	1.06	Z	1.8	9.4	1.89
	Period when Driver is 'On-Seat' (49%)	0.29	0.29	0.59	Z	5.7	>24	1.20
15. Skidsteer Loader	*Entire Operating Period*	0.44	0.28	0.58	Z	6.0	>24	1.71
	Period when Driver is 'On-Seat' (29%)	0.43	0.27	0.43	X / Z	10.7	>24	1.30

Table 4.4 WBV seat data summary (VDV) for machines where driver spent less than 95% of operating period 'on-seat'

Machine / No. / Analysis Period		***Estimated 8-hour VDV ($m/s^{1.75}$)***				***Time to EAV (hr) (VDV)***	***Time to ELV (hr) (VDV)***	***SEAT value***
		X	***Y***	***Z***	***Major axis***			
6. 10-tonne Twin-drum Articulated Vibrating Roller	*Entire Operating Period*	6.1	8.9	14.0	Z	1.4	>24	1.40
	Period when Driver is 'On-Seat' (90%)	5.6	9.0	7.4	Y	8.5	>24	0.85
8. 18-tonne Articulated Loading Shovel	*Entire Operating Period*	14.3	12.5	18.7	Z	0.5	12.8	2.29
	Period when Driver is 'On-Seat' (86%)	14.2	12.5	16.5	Z	0.7	20.9	2.02
11. 2.5-tonne Fork Lift Truck	*Entire Operating Period*	9.3	11.0	21.4	Z	0.3	7.5	0.64
	Period when Driver is 'On-Seat' (52%)	9.3	11.1	19.3	Z	0.4	11.1	0.63
12. 6.5-tonne Fork Lift Truck	*Entire Operating Period*	7.5	8.5	20.1	Z	0.3	9.5	1.37
	Period when Driver is 'On-Seat' (49%)	7.5	8.5	17.9	Z	0.5	15.3	1.21
15. Skidsteer Loader	*Entire Operating Period*	13.6	9.4	24.5	Z	0.2	4.3	1.22
	Period when Driver is 'On-Seat' (29%)	13.6	9.4	23.6	Z	0.2	5.0	1.18

5. DISCUSSION OF RESULTS

In all the following cases, reference should be made to Tables 4.1, 4.2, 4.3 & 4.4 for summary of operator seat vibration magnitudes and operating periods to the Exposure Action Value (EAV) and Exposure Limit Value (ELV). Full details of each machine, its operating application(s) and graphical presentation of the resulting WBV levels, appear in Appendix 1.

5.1 BACKHOE LOADER

Full details of this machine, operating application(s) and resulting WBV levels are presented in Appendix 1.1. When used for trenching / excavating (see Appendix 1.1.2), this machine had the lowest set of whole-body vibration magnitudes in the study, and could be operated continuously without reaching the (a(8)) EAV during a normal working day. When travelling on the highway ('Road Travel') (see Appendix 1.1.3), the vibration magnitudes were also low, but when driven enthusiastically over a rough track ('Load & Carry') (see Appendix 1.1.2), they increased somewhat and the axis with the highest component changed from longitudinal (X) to transverse (Y). Hydraulically-damped suspension of the front loader assembly is a useful way of improving the ride of these machines in transport (pitch frequency about 1 Hz), but this facility was not fitted to the target machine. It is less important that the seat suspension is not effective in reducing the relatively low magnitudes of vertical (Z-axis) vibration from two modes centred on 1 Hz and 2 Hz (SEAT value = 1.2). A possible influence on the vibration magnitudes was driving style, because the operator treated the machine as his own, and was therefore relatively careful.

5.2 3-TONNE SITE DUMPER

Full details of this machine, operating application(s) and resulting WBV levels are presented in Appendix 1.2. When used for somewhat sedate 'Spoil Removal' (shuttle dumping) (see Appendix 1.2.2), this machine showed low magnitudes of whole-body vibration (WBV), arguably within the capacity of the primitive seat suspension. When used for Soil Transport over a moderately-rough roadway, much higher magnitudes were found (see Appendix 1.2.3). A suitable suspended seat could reduce the vertical (Z-axis) vibration component, whose energy is centred at about 2.5 Hz, but the transverse (Y-axis) component would then become the largest. Risk would best be minimised by operator training in 'Best Practice', particularly by encouraging drivers not to be too enthusiastic when driving over longer distances of typical off-road tracks.

5.3 25-TONNE ARTICULATED DUMP TRUCK

Full details of this machine, operating application and resulting WBV levels are presented in Appendix 1.3. Despite what were considered to be moderate – favourable operating conditions, this machine exhibited one of the highest sets of WBV magnitudes of those investigated in this study, the highest component appearing in the transverse (Y) axis, followed (in slightly lower magnitude) by the longitudinal (X) axis (see Table 4.1). The haul road was reported to be relatively well maintained, yet the driver restricted his forward speed because of WBV discomfort. As expected, the suspension seat did little to attenuate the vertical (Z-axis) vibration, whose energy was primarily in the region of 1.5 Hz: this being below the practical attenuation limit for seat suspensions (typically ~ 2 Hz). However the Z-axis component was significantly lower than that in the transverse (Y) and longitudinal (X) axes. The operator would approach the Exposure Limit Value (ELV) during a normal working shift, and probably exceed it if operating conditions were poorer. Risk would best be minimised by operator training in 'Best Practice' and maintenance of haul roads (as was the case in this application).

5.4 BULLDOZER

Full details of this machine, operating application and resulting WBV levels are presented in Appendix 1.4. In 'as found' condition, this machine exhibited the highest WBV levels encountered in the study, passing the ELV in little more than half a day. This was dominated by the vertical (Z-axis) vibration component, as a result of a very badly maintained (and largely dysfunctional) suspension seat.

The vibration encountered had most of its energy at frequencies above 5 Hz; primarily a result of the characteristic vibration frequency spectrum generated by the dozer's track undercarriage (soil conditions being soft / moderate). However, the SEAT value in this instance was 1.16. This application or rather the frequency distribution of vertical (Z) axis vibration energy, places a significant demand upon a suspension seat, albeit one well within its capabilities if properly maintained and replaced at the end of its service life (~ 4000 hrs). This had not occurred in this application, the dozer having reached 8600 operating hours with the original seat. An appropriate seat for such a machine, properly maintained, should have a SEAT value of about 0.6, which would reduce the operator's WBV exposure to a much more moderate level.

5.5 FACE SHOVEL

Full details of this machine, operating applications and resulting WBV levels are presented in Appendix 1.5. For most of its operating time, i.e. when loading rock into dump trucks after blasting (see Appendix 1.5.2), the vibration levels were found to be only moderate, with the largest component in the longitudinal (X) axis. The seat did reduce the vertical (Z-axis) vibration component, which has most of its energy at frequencies above 6 Hz. The vibration magnitude in the vertical (Z-axis) direction was very much higher when the machine 'tracked' (travelled under its own power) from the quarry face to a safety zone, prior to daily blasting (see Appendix 1.5.3). However this activity only takes about 16 – 18 minutes per day and so is of little consequence in a 12 hour shift. During excavating / loading dump trucks, the more important longitudinal (X-axis) vibration component has energy in a band of frequencies between 1 Hz and 5 Hz. There is limited scope for controlling this with fore-and-aft seat suspension and, as in the case of articulated loading shovels, it is important that the cab mounting system (which in this instance incorporated vibration isolation) is so designed that the fore-and-aft shocks generated when the bucket enters the rock pile is not amplified into the rocking motion of the cab. Maintenance of machine cab vibration isolation systems is therefore important.

5.6 TWIN-DRUM ARTICULATED VIBRATING ROLLERS

Full details of these machines, operating applications and resulting WBV levels are presented in Appendices 1.6 and 1.7 for the 10-tonne and 4-tonne rollers, respectively. The WBV magnitudes on both of these machines were very low, with the EAV not being reached in an 8-hour continuous shift (see Tables 4.1 & 4.3). There was little difference in WBV levels experienced by the operators during operation with and without roller vibration 'engaged', because the operator platforms of both machines were effectively isolated and the vibration energy was at frequencies well above 25 Hz (~ 24 Hz and primarily ~ 50 Hz). As discussed in Section 4.2, the 10-tonne roller was found to generate high Z-axis vibration levels during periods when the operator left the seat with the engine still running. It is important that these periods are discounted during data analysis in order to achieve a true determination of operator WBV exposure (see Tables 4.3 & 4.4).

5.7 ARTICULATED LOADING SHOVELS

Full details of these machines, operating applications and resulting WBV levels are presented in Appendices 1.8 and 1.9 for the 18-tonne and 24-tonne loading shovels, respectively. The vibration magnitudes on these machines were strongly affected by the way in which they were used. In all cases, the longitudinal (X-axis) component was the highest, but this could vary between about 0.6 m/s^2 and nearly 1 m/s^2 according to how hard /enthusiastically the bucket was driven into the stockpile, and general operating style (see Tables 4.1 & 4.3). Additionally, it was observed that the machine with the lowest magnitudes of vibration was being used on a less rough ground surface, although both operating surfaces were relatively smooth and perfectly acceptable. The suspension seats on both machines amplified the vertical (Z-axis) vibration (SEAT values = 1.10 – 1.26 depending upon machine & operation). As the energy of this component was centred on a frequency of 2 Hz, it could possibly be better controlled by seat selection: neither seat embodied any suspension capability in the longitudinal (X) axis. However, it is also important that the cab mountings are so designed that the fore-and-aft shocks generated when the machine is driven into a stockpile, is not amplified into a rocking motion of the cab. Potential employer action to minimise operator risk from WBV exposure would include operator training in 'Best Practice' and maintenance of operating surfaces.

5.8 8-WHEELED TRUCK (LORRY)

Full details of this machine, operating application and resulting WBV levels are presented in Appendix 1.10. This vehicle shared the lowest WBV magnitudes in the study. This should not be surprising as it was a road vehicle used mainly on the road. A shorter haul route with more off-highway running at the delivery site would result in higher levels, but from the short off-road section in the cycle recorded, this would increase the exposure only slightly. This was an owner-driven vehicle, and it was observed that the driver was more careful than some of his younger colleagues. The vehicle had a fully suspended cab in addition to chassis suspension. As a result, the level of vertical (Z-axis) vibration in the cab was too low for the seat suspension to operate effectively (SEAT = 1.0), although some of the vibration energy (frequency band 1.5 – 2.5 Hz) was in a range that would be appropriate for a seat suspension to attenuate.

5.9 FORK LIFT TRUCKS

Full details of these machines, operating applications and resulting WBV levels are presented in Appendices 1.11 and 1.12 for the 2.5-tonne and 6.5-tonne fork lift trucks, respectively. Despite apparent differences, the two lift trucks in this study exposed their operators to similar magnitudes of WBV. In both cases the highest component was in the vertical direction (Z-axis), with energy in the frequency range of 4 – 5 Hz. The 2.5 tonne machine was fitted with a very effective suspension seat, which reduced Z-axis vibration by more than 50%. The 6.5 tonne machine was fitted with a cushion seat that gave a 20% increase in Z-axis vibration (see Table 4.3). In both cases the drivers spent as much time off the machine as on it, and frequent dismounts were part of the work task. In both cases there were parts of the ground surface that were particularly rough. This, exacerbated by the hard tyres required for stability, was the factor chiefly influencing the vibration. Risk would best be minimised by appropriate maintenance of the operating surfaces and (on the larger machine) installation of an effective suspension seat.

5.10 1.5-TONNE 360° EXCAVATOR (MINI-DIGGER)

Full details of this machine, operating application and resulting WBV levels are presented in Appendix 1.13. This machine exhibited one of the lowest sets of vibration magnitudes, exposure to which would not result in the Exposure Action Value (EAV) being reached in an 8-hour working day. The highest average rms vibration levels were encountered in the longitudinal (X) axis, due primarily to machine pitching during loading of the attendant site dumper. Peak Z-axis seat acceleration levels recorded were deemed to result from the operator re-entering the cab and sitting down on the seat. The WBV values reported (se Table 4.1) are for continuous use, and so not reduced by any breaks. The owner-operator may have been more careful than someone using a hired machine, but there should be no cause for concern with such a machine when used appropriately in such a (domestic building site) operating application.

5.11 80-TONNE RIGID DUMP TRUCK

Full details of this machine, operating application and resulting WBV levels are presented in Appendix 1.14. This vehicle shared the lowest magnitudes of WBV measured in the study, such that nearly 15 hours of use would have been needed to reach the EAV. However, a number of factors contributed to this that could be different in many opencast mining operations. The haul route was unusually short. This led to a large amount of waiting time, but also enabled the operating surface (haul road) to be well maintained by an on-site grader. Also, the haul route did not include gradients or different geological strata, particularly any rocky sections. The frequency of the main component of vertical vibration, at about 1.5 Hz, is below the range for which seat suspensions can practically provide attenuation. Maintenance of the haul road and control of travel speed are therefore the best ways of avoiding excessive operator WBV exposure.

5.12 SKIDSTEER LOADER

Full details of this machine, operating application and resulting WBV levels are presented in Appendix 1.15. This machine exhibited low whole-body vibration magnitudes (see Table 4.3), and was used intermittently (driver 'on-seat' for 29% of operating period), which is typical for its type when used on domestic building sites. During site levelling and materials handling operations, equal largest rms WBV levels were generated in the longitudinal (X) and vertical (Z) axes, but these were sufficiently low as to require over 10 hours of continuous machine operation in order to exceed the A(8) EAV. As discussed in Section 4.2, this is another machine application where it is important to only consider the period when the operator is present upon the machine and therefore exposed to vibration emitted by it. Vertical (Z-axis) vibration was dominated by energy at around 4 Hz, so an effective suspension seat would be expected to reduce this further.

5.13 WHEELED (MOTOR) SCRAPER

Full details of this machine, operating application and resulting WBV levels are presented in Appendix 1.16. This machine had even higher magnitudes of whole-body vibration than the articulated dump truck, exhibiting similar magnitudes (~ 0.97 m/s^2) in both longitudinal (X) and transverse (Y) axes. In a typical 11-hour shift, the operator's exposure to vibration would approach / reach the A(8) Exposure Limit Value (ELV) in both these axes. Factors contributing to the high WBV levels were the large difference between the mass of the main body of the machine and that of the part incorporating the operator's cab, together with the lack of damping in the tyres, which formed the main suspension elements of the machine.

The frequency of the main component of vertical vibration, at about 1 Hz, is below the range for which seat suspensions can practically provide attenuation: a fact reflected in the resulting SEAT value of 1.33. However, as discussed above, the X and Y axes exhibited the highest vibration magnitudes, both at frequencies of less than 1 Hz. The operators used the machines themselves to smooth the haul route on their return journeys, thereby arguably maintaining the operating surfaces in the best possible condition under the circumstances. This machine / application therefore represents a WBV reduction challenge.

6. POTENTIAL FOR OPERATOR WBV EXPOSURE REDUCTION

6.1 OPERATOR TRAINING AND INFORMATION

In many cases, the greatest influence on the WBV magnitudes encountered was operator behaviour. Three of the four machines with the lowest vibration in the study were owner-operated, or effectively owner-operated, and the cost of maintenance and repairs was a factor in moderating operator behaviour. This influence is not present when machines are hired or are owned by "the company". In these cases, operators might be helped to reduce their exposure to WBV if they were better informed of the potential risks.

However, it should be emphasized that virtually without exception, the operators encountered within this study were professionals of many years experience (and WBV exposure), and so their technique(s) and rates of machine operation had been tailored to suit the requirements of the operation being undertaken, the operating conditions and the resulting level of vibration-induced discomfort (if perceived to be an issue). In one of the most severe examples (articulated dump truck), the operator reported limiting his speed for reasons of WBV discomfort. However, clearly the discomfort level chosen was not low enough to provide the degree of protection deemed necessary by current legislation.

6.2 MAINTENANCE OF GROUND SURFACE

In the case of the rigid dump truck, unusually good maintenance of the haul route was cited as one reason for the low levels of whole-body vibration. It is axiomatic that, other things being equal, a badly maintained haul route will lead to higher WBV exposures than one that is well maintained. However, without suitable information or enforced speed restrictions, drivers are likely to choose to travel at higher speeds on better maintained surfaces. In this study, the articulated dump truck and the wheeled (motor) scraper are examples where high vibration magnitudes were found even though attention was paid to smoothing the haul routes (see Appendices 1.3 & 1.16).

6.3 MACHINE DESIGN

For several of the machine types, careful design of cab vibration isolation mounts, coupled with an effective maintenance programme, can avoid amplifying the pitch motion that occurs when excavating or driving shovels into stockpiles. The aspect of design is recognised by most major manufacturers, but the need for relevant maintenance is not always recognised. For some machines, of which the backhoe loader in travel mode is the best example, the ride can be improved usefully by fitting a damped suspension between the main chassis and a major attachment, such as the front loader assembly. Such 'dynamic ride control' solutions have already been employed with much success upon agricultural tractors, albeit in relation to rear (three-point linkage)-mounted implements, when used in road / farm track travel mode (Scarlett et al., 2005).

6.4 SEAT SUSPENSION

Seat suspensions can provide useful reductions in operator WBV exposure on machines for which the vibration energy in the vertical (Z-axis) direction is present at relatively high frequencies. Skid-steer loaders, dozers and lift trucks are examples with most energy at or above 4 Hz. The dozer example showed the serious effect of a badly maintained / ineffective suspension seat. The two lift trucks showed that a suspension could provide a Z-axis WBV reduction of as much as 50%, whereas a simple cushion seat amplified vertical WBV by 20%.

Increasing machine size (mass) brings with it lower vibration frequencies, and the largest machines have vertical energy at frequencies as low as 1 – 1.5 Hz. Unfortunately this is below the practical attenuation limit for seat suspensions, this being in the region of 2 Hz. However, in such cases, a heavily-damped seat suspension could avoid amplifying vertical vibration, and provide an element of protection against occasional high transient shocks. The 80-tonne rigid dump truck was fitted with an appropriate seat, which returned a rms SEAT value of 1.03 (see Table 4.1). Although the wheeled (motor) scraper reported here exhibited a rms SEAT value of 1.33, a similar machine with a different seat returned 1.02 under similar operating conditions. The articulated dump truck gave SEAT value of 0.91, but this was achieved by eliminating a small high frequency component, not by reducing the dominant Z-axis peak present at 1.5 Hz.

Maintenance and, particularly, replacement of dampers, is an issue with suspended seats which machine owners and operators are almost universally unaware. The (seat manufacturer-stated) expected operational life of a suspended seat is approx. 4000 hours. Unlike agricultural vehicles, whose expected design life is in the region of 10,000 hours, machines in the construction, earthmoving, mining and quarrying industries are subjected to much higher annual usage and are therefore expected achieve 30,000 – 40,000 operating hours during their lifetimes, albeit with interim refurbishment at approx. 15,000 hour intervals. This begs the question as to how many times is a suspension seat replaced in a machine's lifetime? As this component is frequently not mentioned in the machine manufacturer's service schedule, the answer is most probably "not very often". This assumption was confirmed by the observations made during this study.

7. CONCLUSIONS AND RECOMMENDATIONS

WBV exposure analyses have been made on one or two examples of each of 13 different types of machine used in the construction, earthmoving, quarrying and mining industries.

Of these, the following were found to expose operators to low levels of WBV, not exceeding the Exposure Action Value (EAV) in a typical working day:-

- Excavating with either a Backhoe Loader or a 1.5-tonne 360° Excavator (mini-digger);
- Compacting tarmac using a 10-tonne or 4-tonne Twin-Drum Articulated Roller, with or without roller vibration engaged;
- Transport using a 32-tonne 8-wheeled Truck (tipper lorry), including short distances off the highway.

An 80-tonne Rigid Dump Truck in an open-cast mine was also found to generate low levels of WBV emissions, but the operating conditions may have been relatively benign, and higher emission levels might be expected in more common operating conditions. These would probably cause the EAV to be exceeded during a typical working day, but not the Exposure Limit Value (ELV).

Other machines or operations that were found to subject the operator to daily WBV exposure above the EAV, but not approaching the ELV (over a typical working day) were:-

- Backhoe Loader in transport mode;
- 3-tonne Site Dumper transferring soil between an excavator and a local spoil heap;
- Face Shovel loading dump trucks in a rock quarry;
- Fork Lift Trucks used in a concrete products plant or at a colliery surface;
- Skidsteer Loader used for general duties on a domestic building site.

18 and 24-tonne Articulated Loading Shovels would fall into the above category, or might expose operators to levels approaching the ELV, depending on how the machines are used (operating technique and surface condition).

Machines found to expose operators to higher levels of WBV, potentially approaching the ELV in a typical working day included:-

- 3-tonne Site Dumper transporting soil over longer distance of moderate roadway;
- 25-tonne Articulated Dump Truck;
- Wheeled (Motor) Scraper.

A Bulldozer also fell into this last category, but only because its suspension seat had been allowed to fall into a very bad state. With a properly maintained seat, it would probably have come within the second of the above groups.

Suspended seats, if appropriately selected and properly maintained, may provide useful reduction of vertical (Z-axis) whole-body vibration on machines such as Fork Lift Trucks, Site Dumpers and Bulldozers.

The most important factors in controlling / reducing operator exposure to WBV are likely to be adequate information and appropriate training in 'Best Practice'. Maintenance of haul

roads and/or other operating surfaces can help reduce machine WBV emission / operator exposure levels, but only if vehicle travel speeds are also controlled.

Care is required in measuring operator WBV exposure levels in instances when the operator does not spend the entire measurement period (or at least 95% of it) on the vehicle seat.

8. REFERENCES

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APPENDICES

APPENDIX 1:

On-Site Measurements of Machine Whole-Body Vibration Emission and Operator Exposure Levels

Appendix 1.1: Machine No.1 – JCB 4CX Super Wheeled Backhoe Loader

A1.1.1 Operational Details

Date: 21st July 2004

Location: Redevelopment of small farmyard and immediate surrounding land, on outskirts of Diss, Norfolk

Machine owner: GN Rackham & Sons
(medium sized house builder, identified by FMB)
Stanley Road
Diss
Norfolk

Machine Make: JCB
Model: 4 CX Super 180° Excavator (Backhoe Loader)
Registration: KC02 FZV
Age: 2002
Mass:- 8880 kg
Condition: Overall good. Machine undertakes approximately 1000 hours work per annum with one operator dedicated to the machine
Operator's name: Ron
Weight: 92 kg

Tyre size/make: Stomil 16.9 28 tubeless, 12 ply all round

Tyre pressures: 30 psi except rear n/s = 20 psi

Vehicle Suspension: No suspension but full width iso-mounted cab.

Seat Suspension: Isringhausen mechanical scissor-type spring and damper Z-axis suspension seat, set relatively firmly by operator choice: also has X axis mechanical spring & damper suspension, but locked and inoperable during machine operation. Seat fitted with inertia reel lap-type seatbelt, but not used by operator. Vehicle seat in good overall condition reflecting overall extremely good condition of machine and high standard of care and maintenance employed by operator.

WBV Instrumentation:
Seat:- SRI ICP-type PCB 356B40 in seat pad plus operator seat presence switch
Floor:- SRI Floor Box No.3 attached to seat mounting
Both pieces of instrumentation feeding through Larson Davis Human Vibration Meters (LD 215 – Floor) & (LD 272 – Seat) and recording directly to Teac DR-C2 PC-card recorder. **(NB:- error with Z-axis LD 215 (floor) sensitivity & connection)**

Site Operations:-

1) **Trenching:-** Excavating footings for 15m x 7m house using backhoe (to load 3-tonne site dumper). Soil conditions relatively soft top soil, agricultural type conditions, but soft, wet clay @ bottom of trench.
2) **Load & Carry:-** Moving spoil along farm track to new location on-site. Filling site dumper with backhoe, then fills own front bucket & transports material ~330m to new heap. Track relatively smooth - pot holes absent, maintained in good condition.
3) **Road Travel:-** JCB travels (unladen) down short access track to public road and then on to a (~6-7min duration) road circuit around local estate

Operational Record:-

Recording started: **10:22 hrs** **Duration:-** **5:01 hrs:mins**
Recording stopped: **15:23 hrs**

Data Analysis Periods:-

1) **Trenching / Excavating** **0:01 – 2:39 hrs:mins** **Duration = 2:40 hrs:mins**
2) **Load & Carry** **4:15 – 4:46 hrs:mins** **Duration = 32 mins**
3) **Road Travel** **4:51 – 4:58 hrs:mins** **Duration = 8 mins**

Time (hrs:mins)	Duration (hrs:mins	Activity : Comments
10:30	**0:08**	Digging of foundation for new house on previously levelled green field site at rear of small old farmstead between temporary buildings currently being dismantled.
10.32	**0:10**	Operation recommences:- JCB 4CX using backhoe to dig building foundations and fill 3-tonne Thwaites Alldrive 2000 dumper truck.
11.12	**0:50**	First trench completed – excavator now repositioning ready for new trench to be dug.
11.13	**0:51**	Small amount of front-loader work completed pushing up spoil heap prior to starting new trench perpendicular to existing trench.
11.19	**0:57**	Operator dismounts momentarily to move debris to permit manoeuvring of machine.
11.30	**1:08**	Operator dismounts from excavator to remark site. Re-enters vehicle 30 seconds later.
11.32	**1:10**	Complete second trench, repositions machine in readiness for third digging operation.
11.38	**1:16**	Operator dismounts
11.39	**1:17**	Operator returns to machine – operation recommences. Dumper filled on average once every five minutes.
12.00	**1:38**	Operator dismounts momentarily to remark site.
12.01	**1:39**	Operator re-enters machine and recommences operation.
12.07	**1:45**	Operator dismounts momentarily, re-enters cab within 30-45 seconds.
12.10	**1:48**	Excavator uses front bucket to push up spoil heap previously deposited by dumper during the previous operations.
12.11-12.12	**1:49 – 1:50**	Excavator returns to backhoe operation digging trench perpendicular to existing main trenches.
12.16	**1:54**	Operator dismounts momentarily, returns to cab within 30 seconds.
12.34	**2:12**	Excavator pushing up soil on spoil heap with front bucket, pauses momentarily.
12.36	**2:14**	Spoil heap, heaping with excavator front bucket recommences.
12.37	**2:15**	Returns to trench operation, excavating final trench of 15x 7m house.
13.00	**2:38**	Operation stopped for lunch.
13.50-13.55	**3:28 – 3:33**	Lunch break over. Trenching recommences
14.17	**3:55**	Operator momentarily gets out of cab and returns and recommences trenching operation
14.23	**4:01**	Trenching operation complete.
14.25-14.35	**4:03 – 4:13**	Difficulty with Larson Davies Number 215 (floor) output. Excessively high Z-axis acceleration level. Suspect due to faulty wiring within new accelerometer unit box. Have now wired directly in to previous die-cast metal interface box for floor box unit and also disconnected and reconnected floor box unit plug.
14:36	**4:14**	Teac stopped and started to start new data file (No 01)
14.37	**4:15**	Recommence operation - **Second operation of day** - loading dumper with backhoe from spoil heap. Then subsequently filling excavator front bucket

		from soil heap and both vehicles transporting spoil down farm track to dumping area.
14.39	**4:17**	Dumper loaded - excavator now fills front bucket and prepares to travel to dumping area. Approximate travel speed of excavator in region of 8 mph plus probably nearer 10 mph. Dumper somewhat slower.
14.41-14.42	**4:19 – 4:20**	Spoil dumped - vehicles on return path back to soils heap to refill. Dumper speed close to maximum, also approaching 10 mph.
14.44	**4:22**	Loading dumper with backhoe of loader, entire roadway track relatively smooth, good condition.
14.50	**4:28**	Having dumped soil returning to soils heap, both dumper and digger.
14.51	**4:29**	Excavator returning along farm track to soils heap. JCB behaviour during track travel smooth, sedate despite relatively high travel speed either when front bucket laden or unladen.
14.52-14.53	**4:30 – 4:31**	Excavator returns to heap using backhoe to load dumper.
14.53-14.54	**4:31 – 4:32**	Loading commenced JCB now loads its own front bucket.
14.54	**4:32**	Front bucket loaded, begins travel to destination heap along farm track.
14.56-14.57	**4:34 – 4:35**	Tipping at destination heap.
14.58	**4:36**	JCB returning from destination heap to source heap along farm track.
15.00	**4:38**	JCB now returned to source heap filling dumper with backhoe.
15.01	**4:39**	Loading complete, JCB now fills front bucket from spoil heap
15.02	**4:40**	JCB starts trip to destination heap
15.04	**4:42**	Dumping at destination heap.
15.05	**4:43**	Dumper returns along track.
15.07	**4:45**	Digger returns along track
15.13	**4:51**	**New operation (No.3): JCB Road Travel:-** Initially down farm track to road and then on to road circuit around local estate. TEAC stopped and started to give new file name (should be No.2)
15.19	**4:57**	JCB returns from road circuit.
15.23	**5:01**	Data recorders stopped

Figure A1.1.1 JCB 4CX Super backhoe loader at work on-site

A1.1.2 JCB 4CX Super Backhoe Loader WBV Data:- Trenching / Excavating

Larson Davis HVM100	SN:00215		Day	Month	Year
Location:	***Floor***		***21***	***Jul***	***4***
Machine:	JCB 4CX Super Backhoe Loader				
Reg No:	KC02 FZV			Start time:	09:22
Task:	Trenching / Excavating				
Place:	Diss	**!!! PROBLEM WITH Z-AXIS SCALING !!!**			
		!!! PROBLEM WITH Z-AXIS CONNECTION !!!			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
02:40	**4.2**	**4.1**	**-**	**-**
8-hr est tot	*5.5*	*5.3*	-	-

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.22	***0.19***	**-**	**-**

Estimated values	**VDV**	**rms/A8**
Time to EAV (hr):	-	39.5
Time to ELV (hr):	-	209.2

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
43.26	47.18	-	-

Larson Davis HVM100	SN:00272		Day	Month	Year
Location:	***Seat***		***21***	***Jul***	***4***
Machine:	JCB 4CX Super Backhoe Loader				
Reg No:	KC02 FZV			Start time:	09:22
Task:	Trenching / Excavating				
Place:	Diss				

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
02:40	**5.5**	**5.1**	**7.4**	**10.5**
8-hr est tot	*7.2*	*6.7*	*9.8*	*13.8*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.29	***0.24***	***0.21***	***0.43***

Estimated values	**VDV**	**rms/A8**
Time to EAV (hr):	6.1	23.3
Time to ELV (hr):	172.0	123.3

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
4.52	4.94	16.10	16.10

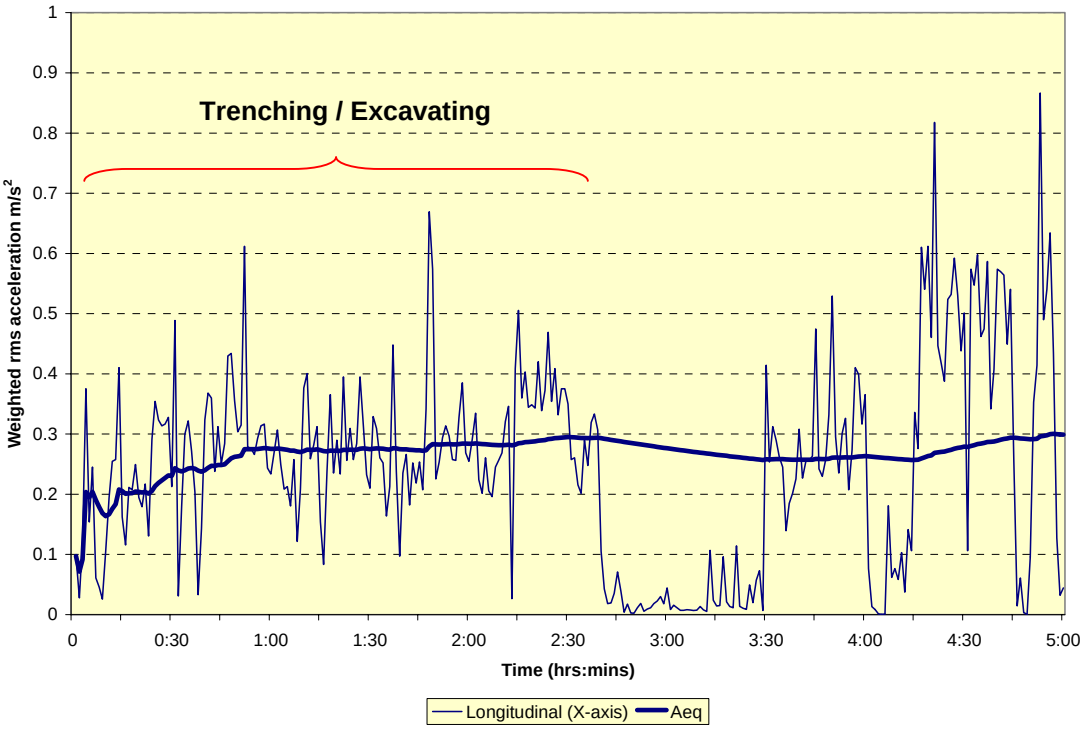

Figure A1.1.2 JCB 4CX backhoe loader:- time history of weighted 1-minute rms seat accelerations (X-axis) and equivalent continuous rms acceleration (Aeq) – entire measurement period

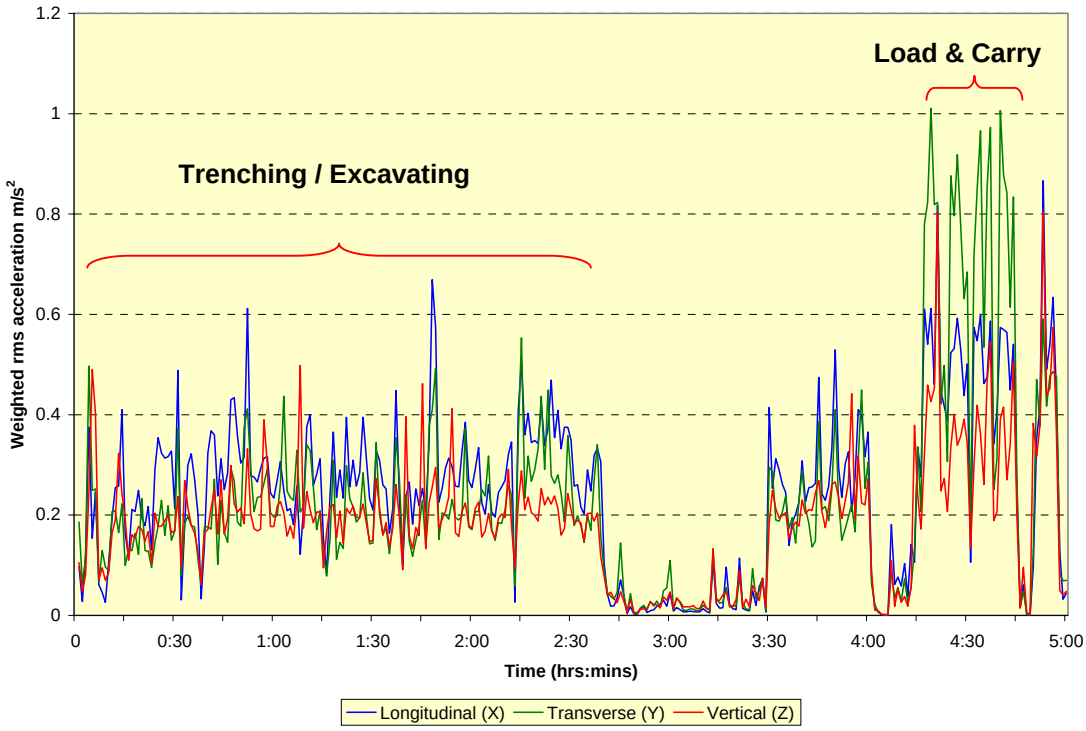

Figure A1.1.3 JCB 4CX backhoe loader:- time histories of weighted 1-minute rms seat accelerations (X, Y and Z-axes) – entire measurement period

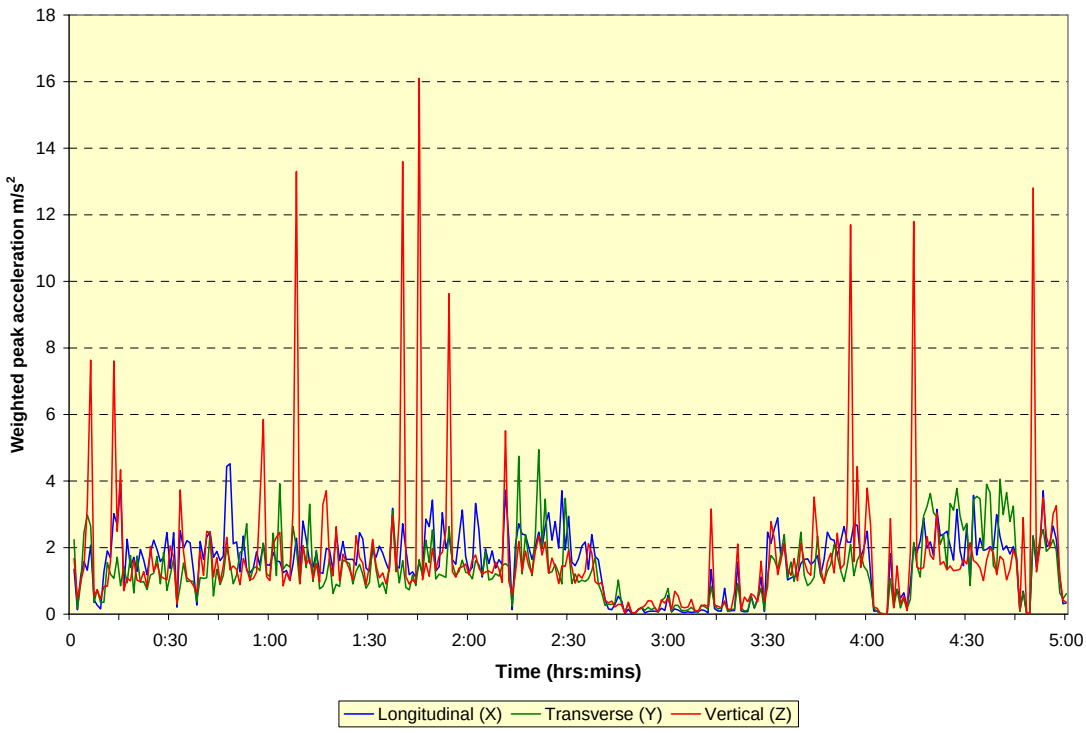

Figure A1.1.4 JCB 4CX backhoe loader:- time histories of weighted 1-minute peak seat accelerations (X, Y and Z-axes) – entire measurement period

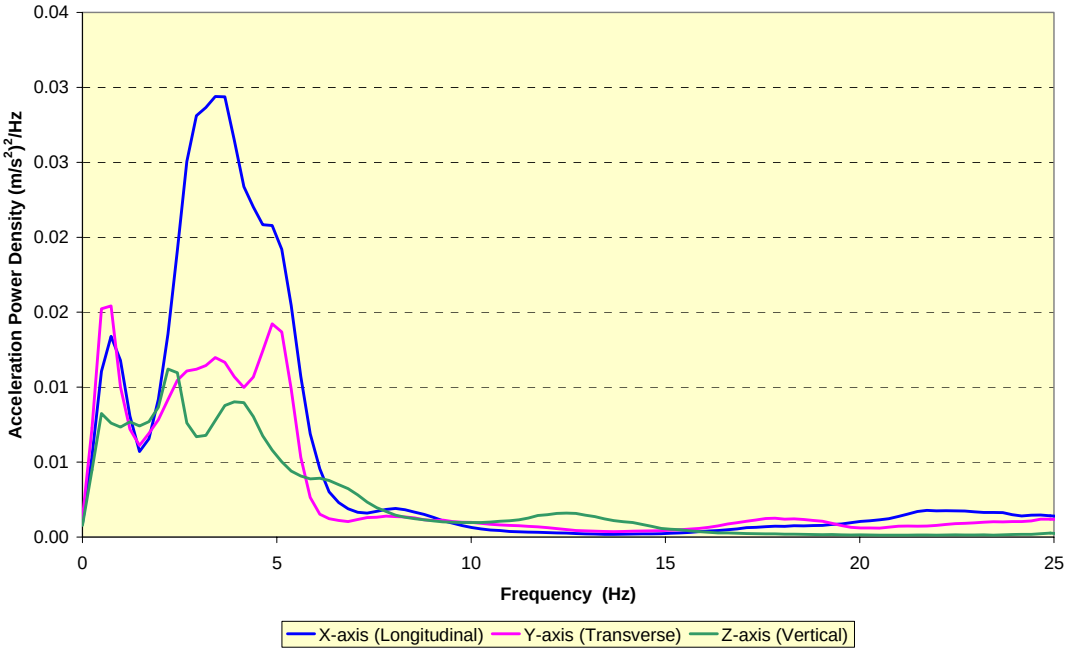

Figure A1.1.5 JCB 4CX backhoe loader:- acceleration power spectral density (seat) – road travel

NB:- Due to absence of vertical (Z) axis 'floor' vibration data (due to recording system fault), it is not possible to present further frequency or seat performance data for the trenching / excavating application.

A1.1.3 JCB 4CX Super Backhoe Loader WBV Data:- 'Load & Carry'

Larson Davis HVM100	SN:00215	Day	Month	Year
Location:	***Floor***	***21***	***Jul***	***4***
Machine:	JCB 4CX Super Backhoe Loader			
Reg No:	KC02 FZV		Start time:	14:37
Task:	Load & Carry			
Place:	Diss			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
00:32	**3.5**	**5.0**	**3.5**	**7.0**
8-hr est tot	*6.8*	*9.8*	*6.8*	*13.7*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.35	***0.51***	***0.33***	***0.70***

Estimated values	**VDV**	**rms/A8**
Time to EAV (hr):	6.0	7.7
Time to ELV (hr):	171.4	40.7

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
2.83	3.01	34.20	34.00

Larson Davis HVM100	SN:00272	Day	Month	Year
Location:	***Seat***	***21***	***Jul***	***4***
Machine:	JCB 4CX Super Backhoe Loader			
Reg No:	KC02 FZV		Start time:	14:37
Task:	Load & Carry'			
Place:	Diss			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
00:32	**4.8**	**7.0**	**3.8**	**9.3**
8-hr est tot	*9.5*	*13.8*	*7.5*	*18.4*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.50	***0.71***	***0.37***	***0.94***

Estimated values	**VDV**	**rms/A8**
Time to EAV (hr):	1.5	4.0
Time to ELV (hr):	43.0	21.1

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
3.57	4.06	3.04	4.13

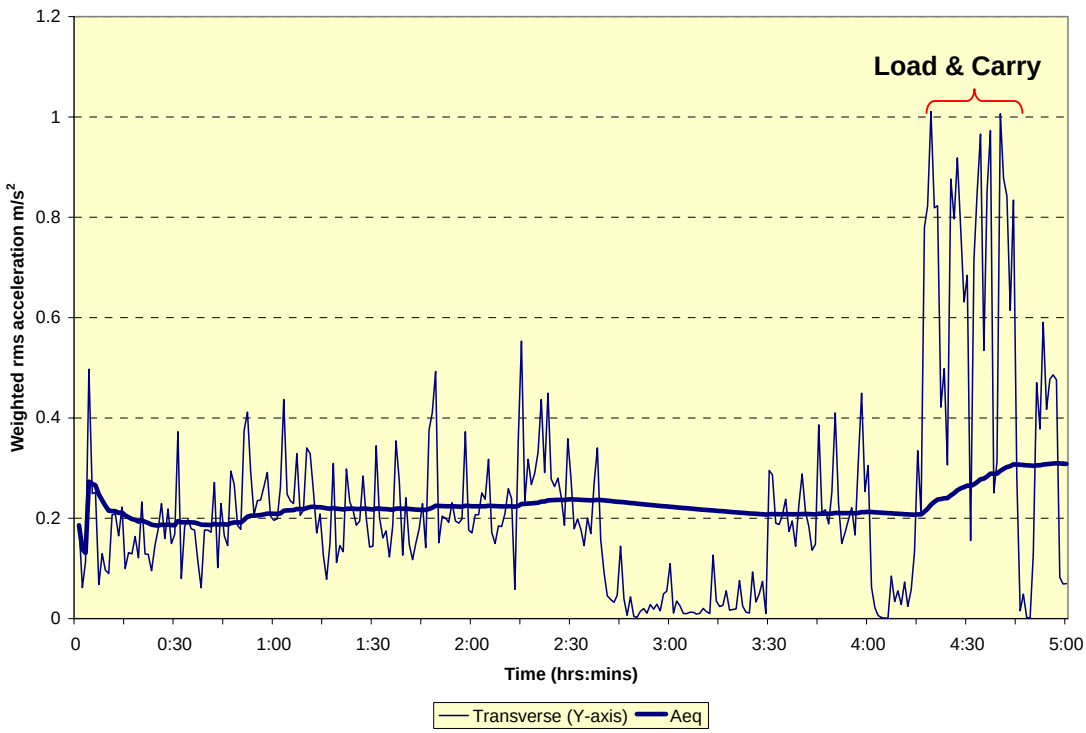

Figure A1.1.6 JCB 4CX backhoe loader:- time history of weighted 1-minute rms seat accelerations (Y-axis) and equivalent continuous rms acceleration (Aeq) – entire measurement period

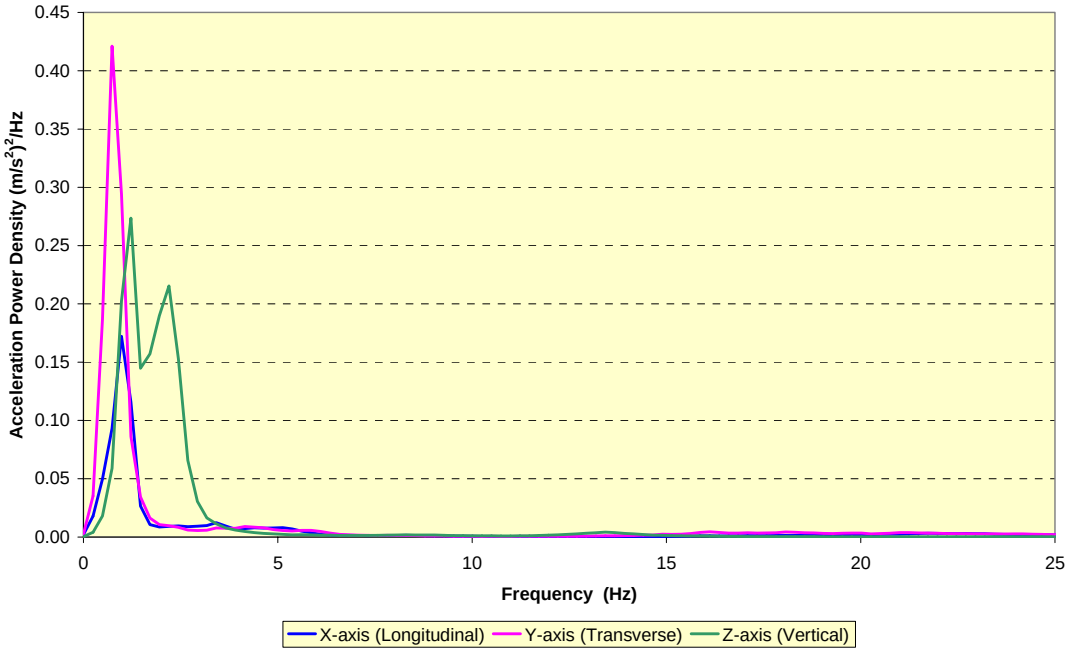

Figure A1.1.7 JCB 4CX backhoe loader:- acceleration power spectral density (seat) – 'load & carry' operation

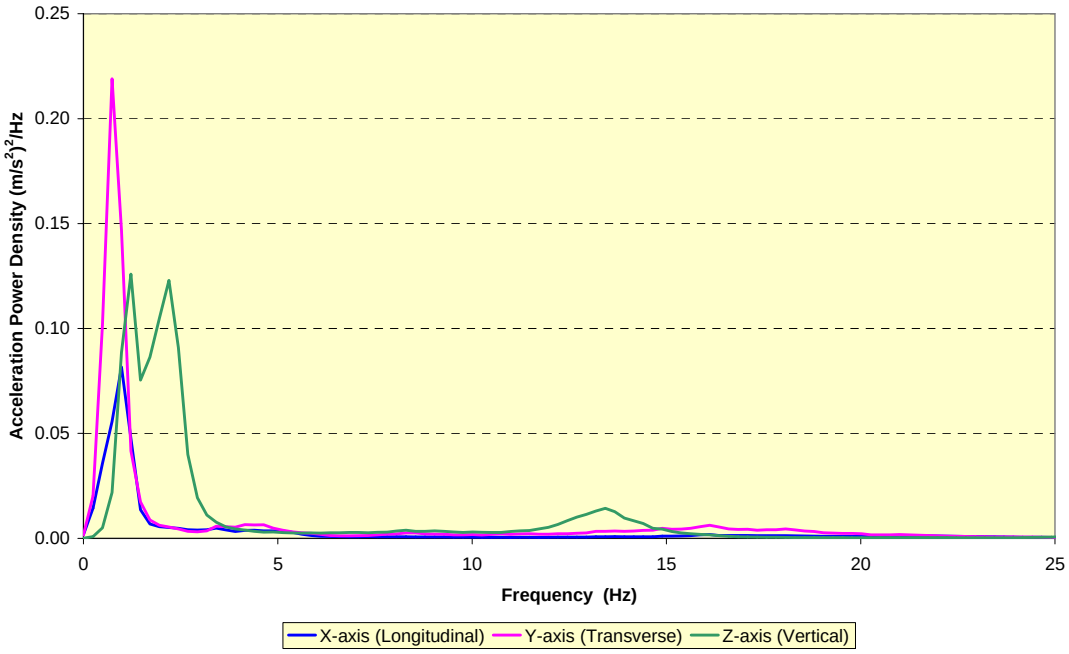

Figure A1.1.8 JCB 4CX backhoe loader:- acceleration power spectral density (floor) – 'load & carry' operation

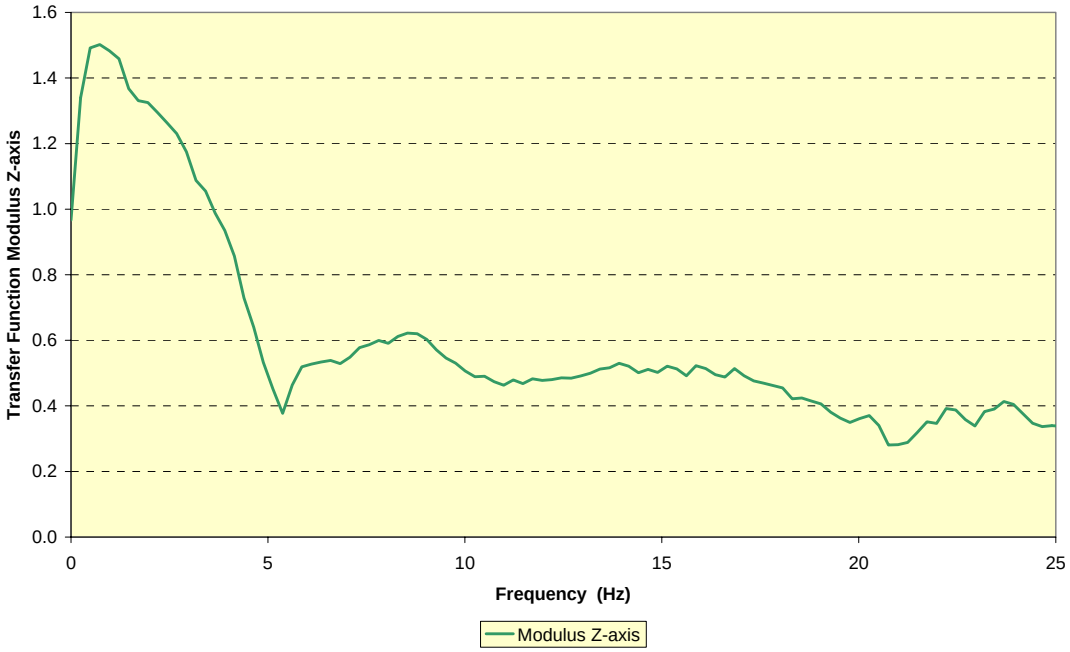

Figure A1.1.9 JCB 4CX backhoe loader:- seat transfer function – Magnitude – whilst performing 'load & carry' operation

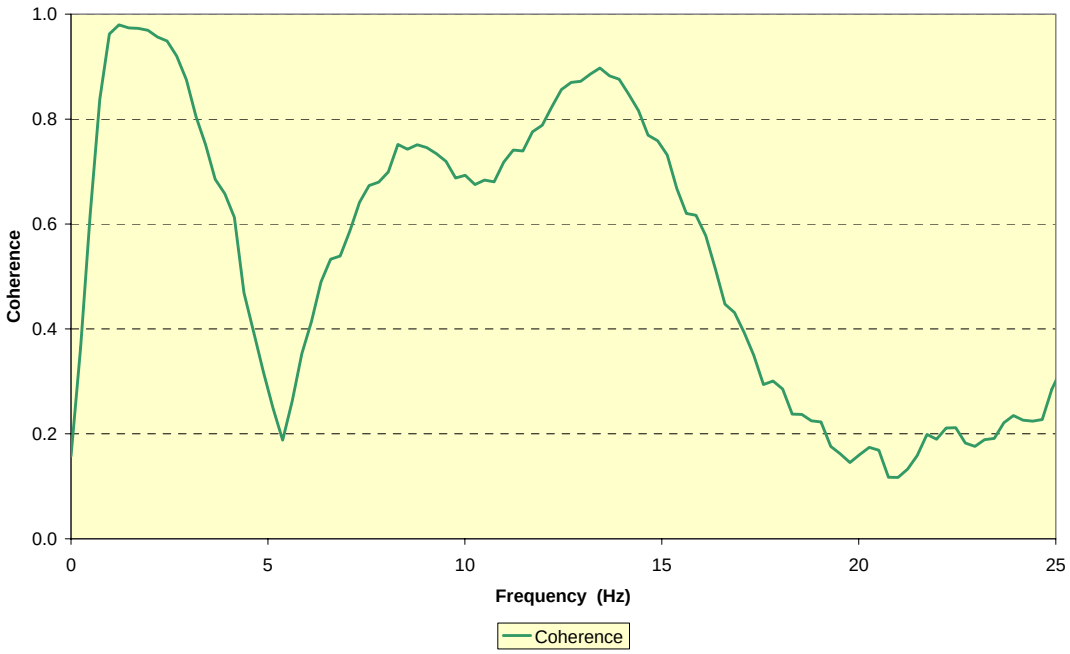

Figure A1.1.10 JCB 4CX backhoe loader:- seat transfer function – Coherence – whilst performing 'load & carry' operation

A1.1.4 JCB 4CX Super Backhoe Loader WBV Data:- Road Travel

Larson Davis HVM100	SN:00215	Day	Month	Year
Location:	***Floor***	***21***	***Jul***	***4***
Machine:	JCB 4CX Super Backhoe Loader			
Reg No:	KC02 FZV		Start time:	15:13
Task:	Road Travel			
Place:	Diss			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
00:08	**2.1**	**2.2**	**2.7**	**4.0**
8-hr est tot	*5.7*	*6.0*	*7.5*	*11.2*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.31	***0.33***	***0.39***	***0.70***

Estimated values	**VDV**	**rms/A8**
Time to EAV (hr):	17.5	13.4
Time to ELV (hr):	495.2	71.1

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
2.24	1.86	3.03	4.2

Larson Davis HVM100	SN:00272	Day	Month	Year
Location:	***Seat***	***21***	***Jul***	***4***
Machine:	JCB 4CX Super Backhoe Loader			
Reg No:	KC02 FZV		Start time:	15:13
Task:	Road Travel			
Place:	Diss			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
00:08	**3.6**	**2.9**	**3.3**	**5.7**
8-hr est tot	*9.9*	*8.1*	*9.2*	*15.7*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.52	***0.45***	***0.47***	***0.83***

Estimated values	**VDV**	**rms/A8**
Time to EAV (hr):	5.7	7.3
Time to ELV (hr):	161.4	38.7

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
3.71	2.55	3.50	4.25

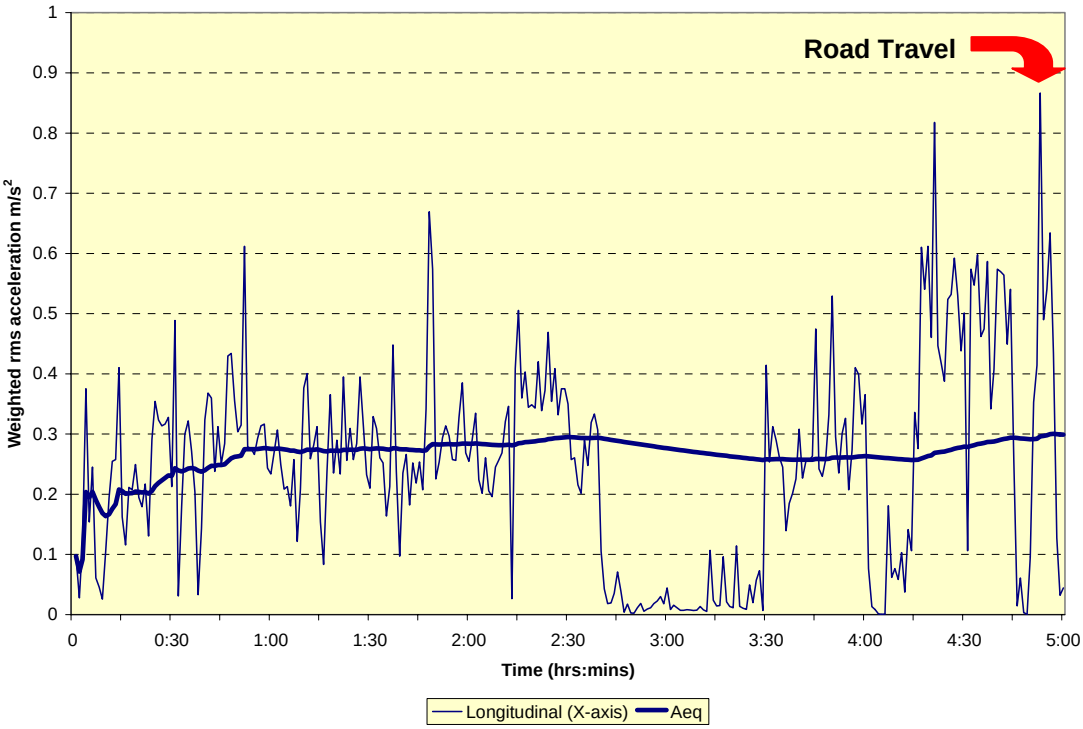

Figure A1.1.11 JCB 4CX backhoe loader:- time history of weighted 1-minute rms seat accelerations (X-axis) and equivalent continuous rms acceleration (Aeq) – entire measurement period

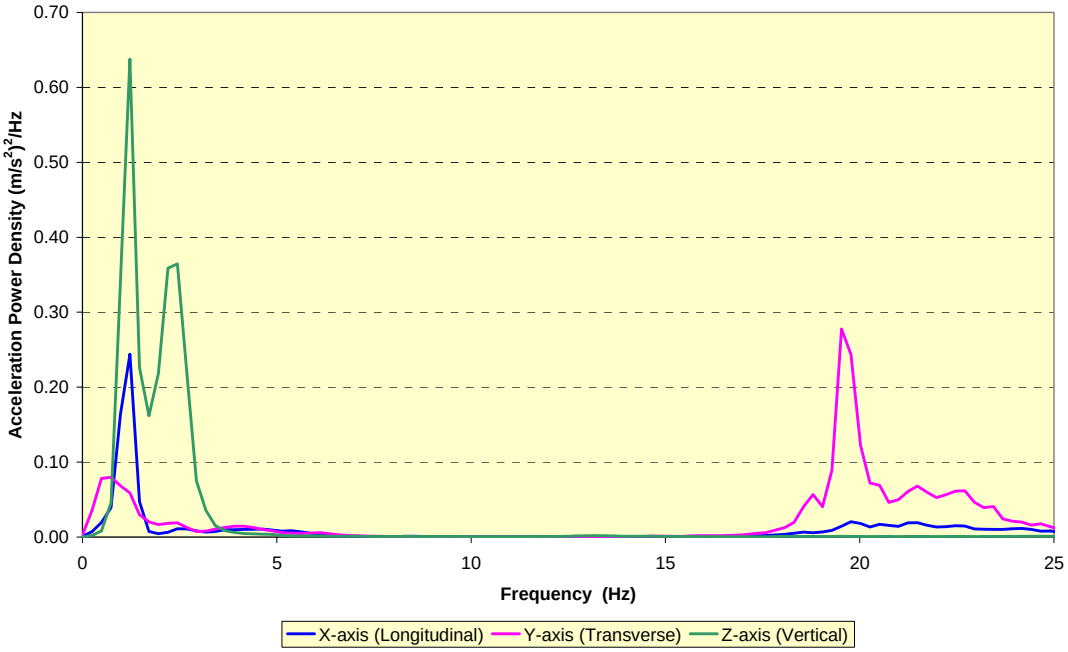

Figure A1.1.12 JCB 4CX backhoe loader:- acceleration power spectral density (seat) – road travel

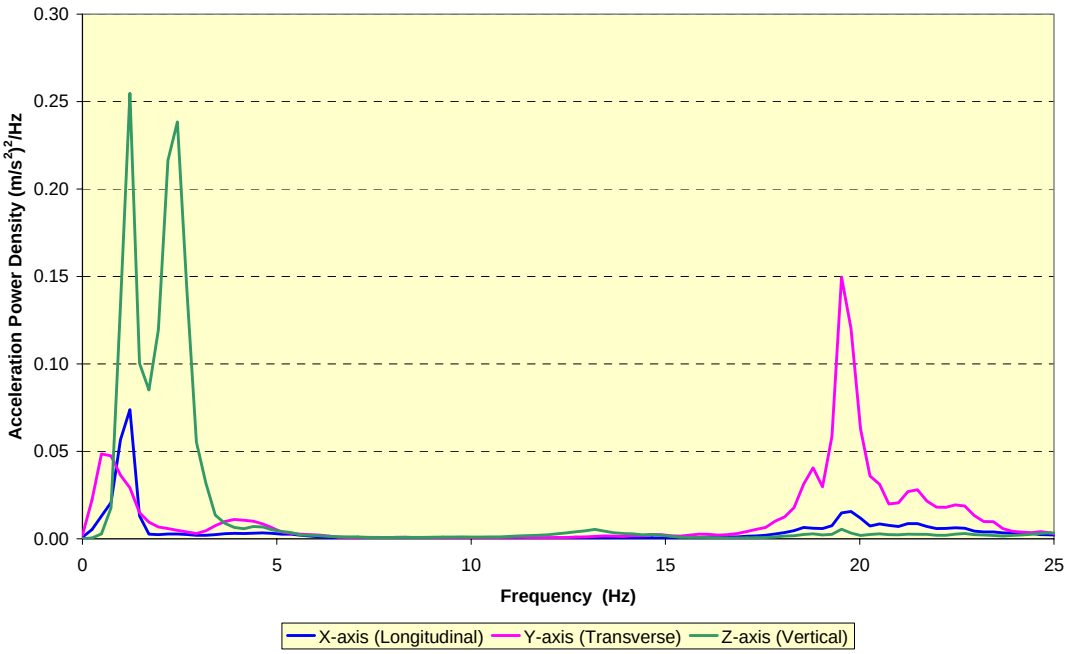

Figure A1.1.13 JCB 4CX backhoe loader:- acceleration power spectral density (floor) – road travel

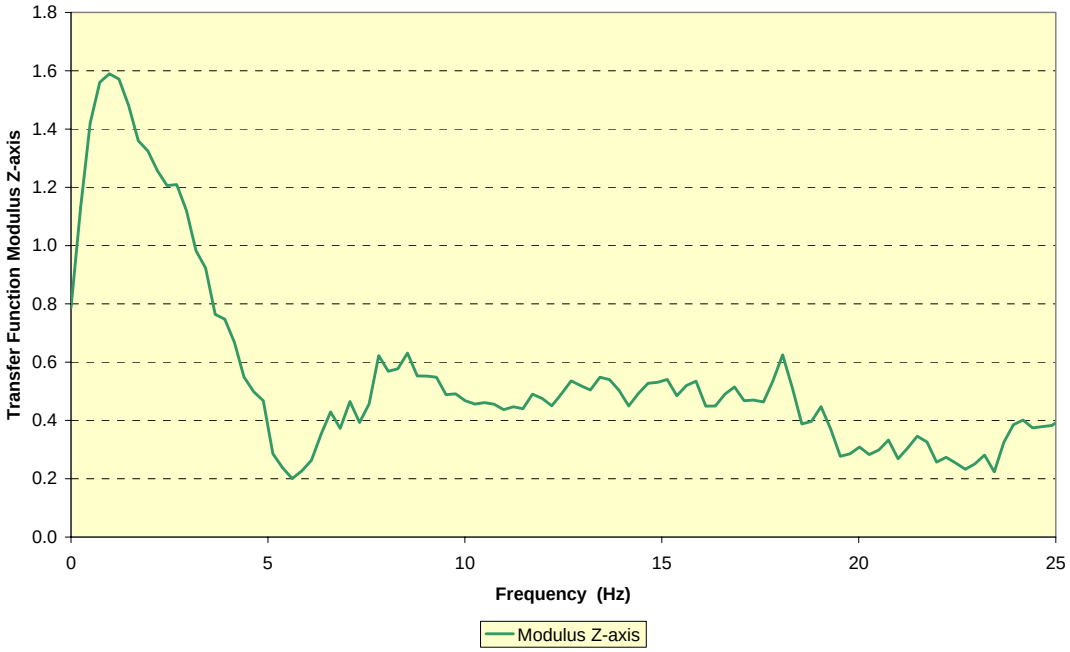

Figure A1.1.14 JCB 4CX backhoe loader:- seat transfer function – Magnitude – whilst undertaking road travel

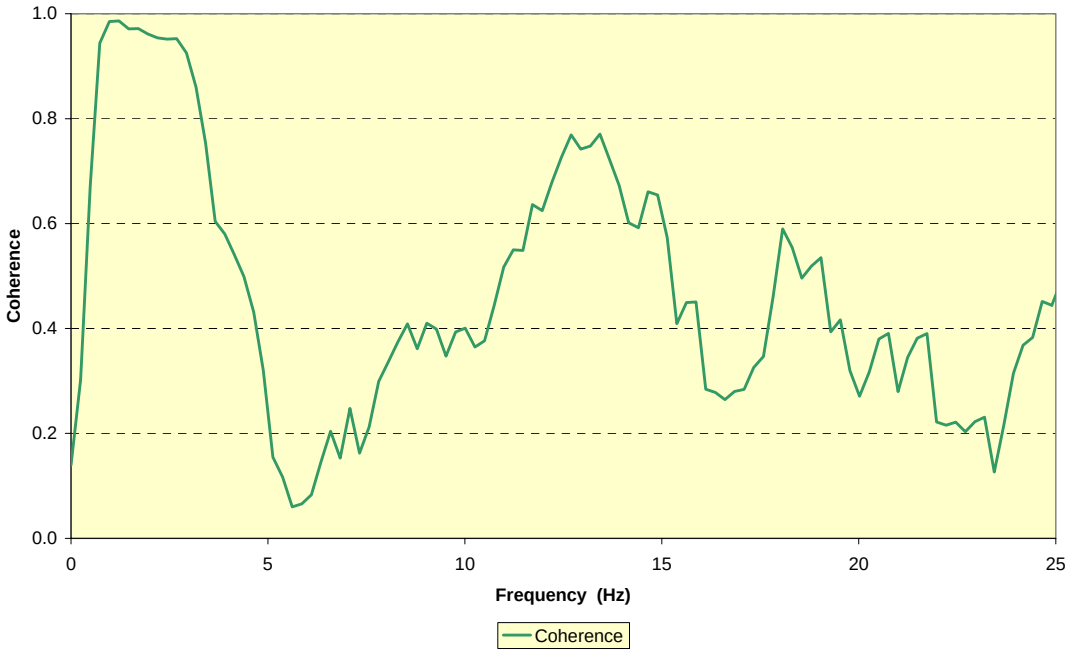

Figure A1.1.15 JCB 4CX backhoe loader:- seat transfer function – Coherence – whilst undertaking road travel

Appendix 1.2: Machine No.2 – Thwaites Alldrive 7000 3-tonne Articulated Site Dumper

A1.2.1 Operational Details

Date: 21st July 2004

Location: Redevelopment of small farmyard and immediate surrounding land, on outskirts of Diss, Norfolk

Machine owner: GN Rackham & Sons
(medium sized house builder, identified by FMB)
Stanley Road
Diss
Norfolk

Machine Details:

Make:	Thwaites
Model:	Alldrive 7000
Weight:	
Capacity:	3,000 kg
Power:	
Year of build:	
Condition:	Old and difficult to start, tyres well worn.
Tyre size/make:	
Tyre pressures:	1 bar at rear, 1.5 bar at front.

Vehicle Suspension: None.

Seat Suspension: The seat consisted of a KAB P2 upper attached to the machine by a pivot below the front edge and supported at the rear on a pair of small coil springs with no damping.

Operator: Weight:- 91.9 kg

WBV Instrumentation (transducers):

Seat:- ICP type PCB 356B40 in seat pad plus operator seat presence switch
Floor: ICP type PCB 356B40 attached by magnetic clamp to structure below seat pan

Site Operations:-

Measurements comprised 3 hours during which house footings were dug, followed by 30 minutes during which both the Site Dumper and the Backhoe Loader were used to move spoil from the immediate, short-term spoil heap to a yard convenient to the site where it could be stored for later use

1) **Spoil Removal:-** While a Backhoe Loader was excavating footings for 15m x 7m house using backhoe, the Site Dumper removed the spoil to a nearby spoil heap ('V-shaped motion'). The distance between the Loader and the heap varied from 30m down to less than 10m. The cycle time was almost constant at about 4 minutes. The driver remained in his seat most of the time.

2) **Soil Transport:-** Moving spoil along farm track to new location on-site. Total distance about 330m; cycle time about 8 minutes. Track rel8tively smooth - pot holes absent, maintained in good condition.

Operational Record:-

Recording started: **10:29 hrs** **Duration:-** **4:39 hrs:mins**
Recording stopped: **15:08 hrs**

Data Analysis Periods:-

1) **Spoil Removal** **3:26 – 3:56 hrs:mins** **Duration = 31mins**
2) **Soil Transport** **4:08 – 4:30 hrs:mins** **Duration = 23 mins**

Time (hrs:mins)	Duration (hrs:mins)	Activity : Comments
10:29	**0:00**	Recorders started.
10.30	**0:01**	Move into position to receive first load from Backhoe.
10.35	**0:06**	Travel to spoil heap.
		Continues for 31 trips to spoil heap, with occasional manoeuvres to accommodate re-positioning of Backhoe.
12:59	**2:30**	Stop for lunch break.
13:52	**3:23**	Started engine and continued for 8 more trips to spoil heap
14:22	**3:53**	Trenching operation complete. Engine off.
14:26	**3:57**	Dumper bucket loaded with spoil for transport to long-term heap.
15:05	**4:36**	Return after 4th cycle of load-haul-dump and switch off engine.Operator dismounts
15:08	**4:39**	Recorders stopped.



Figure A1.2.1 Thwaites 3-tonne articulated site dumper undertaking 'spoil removal'

Figure A1.2.2 Thwaites 3-tonne articulated site dumper undertaking ‘soil transport’

A1.2.2 Thwaites 3-tonne Articulated Site Dumper: WBV Data:- Spoil Removal

Larson Davis HVM100	SN:00385	Day	Month	Year
Location:	***Floor***	***21***	***Jul***	***4***
Machine:	Site dumper Thwaites 7000			
Reg No:			Start time:	13:55
Task:	Spoil Removal (Shuttle-Dump)			
Place:	Diss			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
00:31	**4.9**	**5.3**	**5.6**	**9.1**
8-hr est tot	*9.8*	*10.5*	*11.1*	*18.1*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.38	***0.49***	***0.55***	***0.83***

Estimated values	**VDV**	**rms/A8**
Time to EAV (hr):	3.7	6.6
Time to ELV (hr):	103.6	35.1

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
4.73	4.49	5.27	5.28

Larson Davis HVM100	SN:00386	Day	Month	Year
Location:	***Seat***	***21***	***Jul***	***4***
Machine:	Site Dumper Thwaites 7000			
Reg No:			Start time:	13:55
Task:	Spoil Removal (Shuttle-Dump)			
Place:	Diss			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
00:31	**5.6**	**5.0**	**6.5**	**9.9**
8-hr est tot	*11.1*	*9.9*	*13.0*	*19.7*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.42	***0.53***	***0.43***	***0.79***

Estimated values	**VDV**	**rms/A8**
Time to EAV (hr):	1.9	7.2
Time to ELV (hr):	55.3	38.1

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
6.57	4.28	6.72	6.96

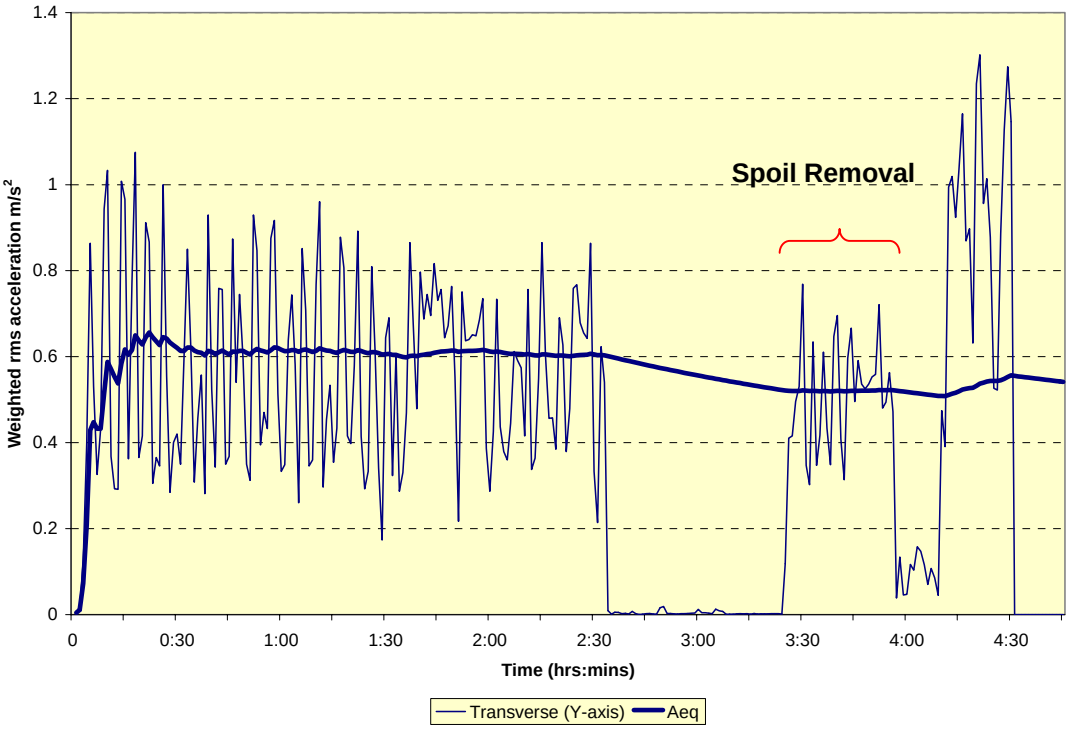

Figure A1.2.3 Thwaites 3-tonne articulated site dumper:- time history of weighted 1-minute rms seat accelerations (Y-axis) and equivalent continuous rms acceleration (Aeq) – entire measurement period

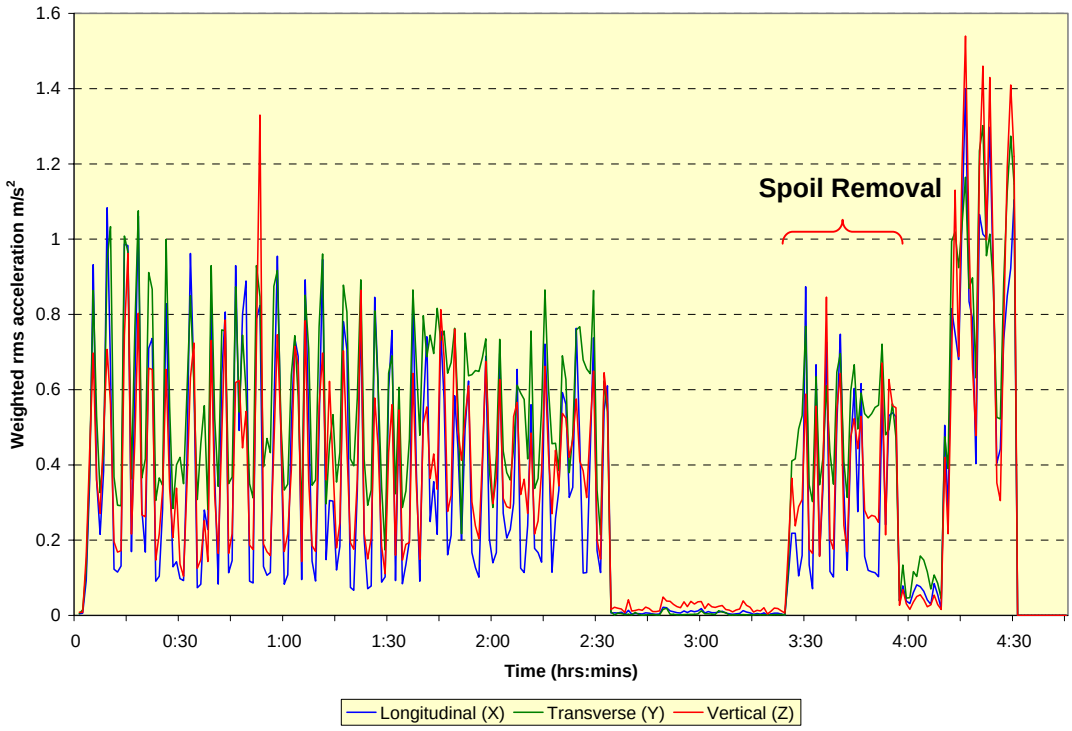

Figure A1.2.4 Thwaites 3-tonne articulated site dumper:- time histories of weighted 1-minute rms seat accelerations (X, Y and Z-axes) – entire measurement period

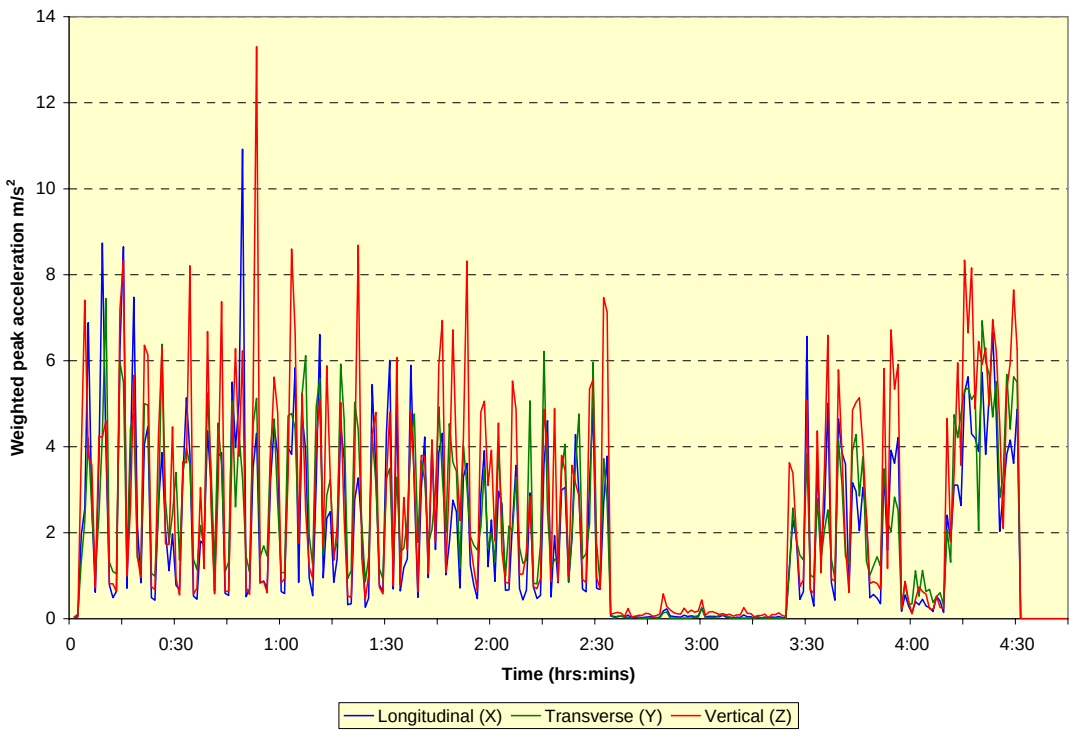

Figure A1.2.5 Thwaites 3-tonne articulated site dumper:- time histories of weighted 1-minute peak seat accelerations (X, Y and Z-axes) – entire measurement period

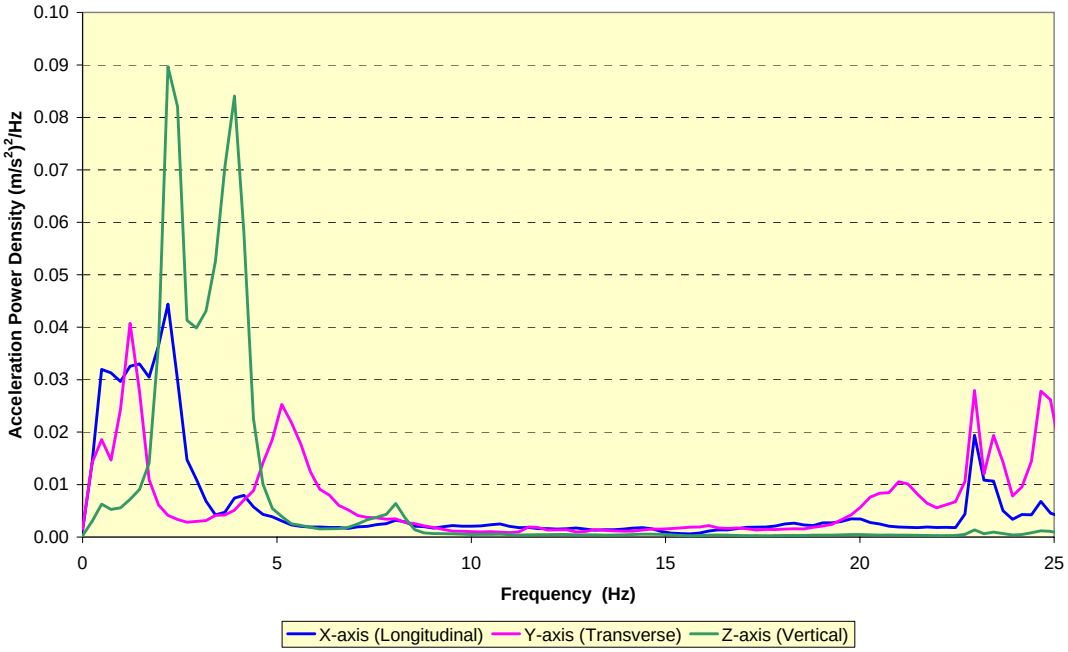

Figure A1.2.6 Thwaites 3-tonne articulated site dumper:- acceleration power spectral density (seat) – spoil removal (shuttle dumping)

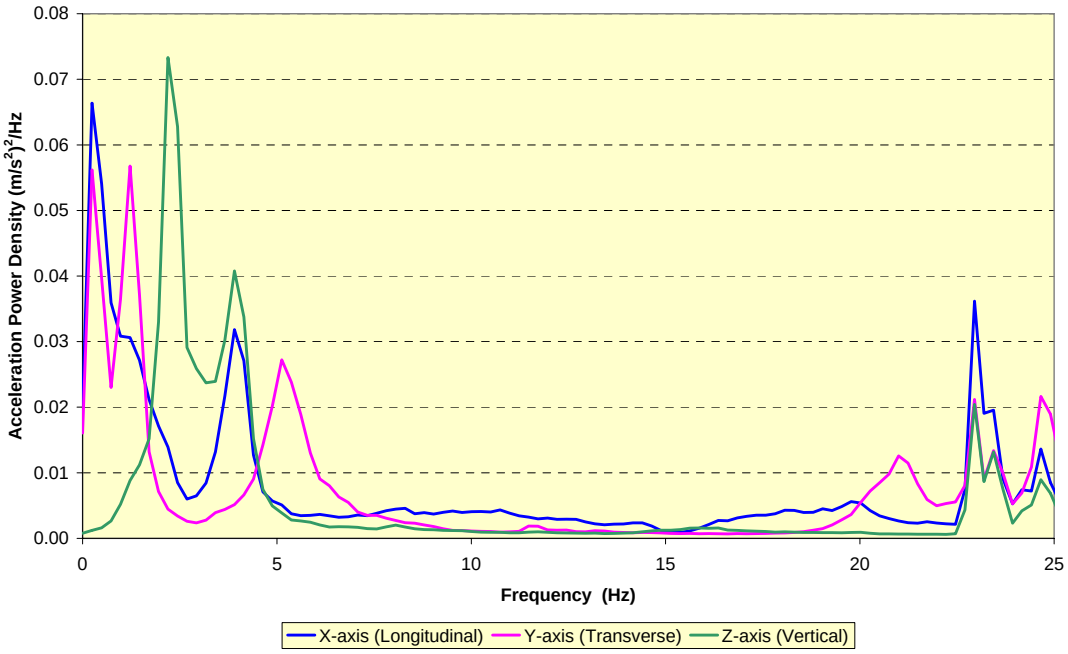

Figure A1.2.7 Thwaites 3-tonne articulated site dumper:- acceleration power spectral density (floor) – spoil removal (shuttle dumping)

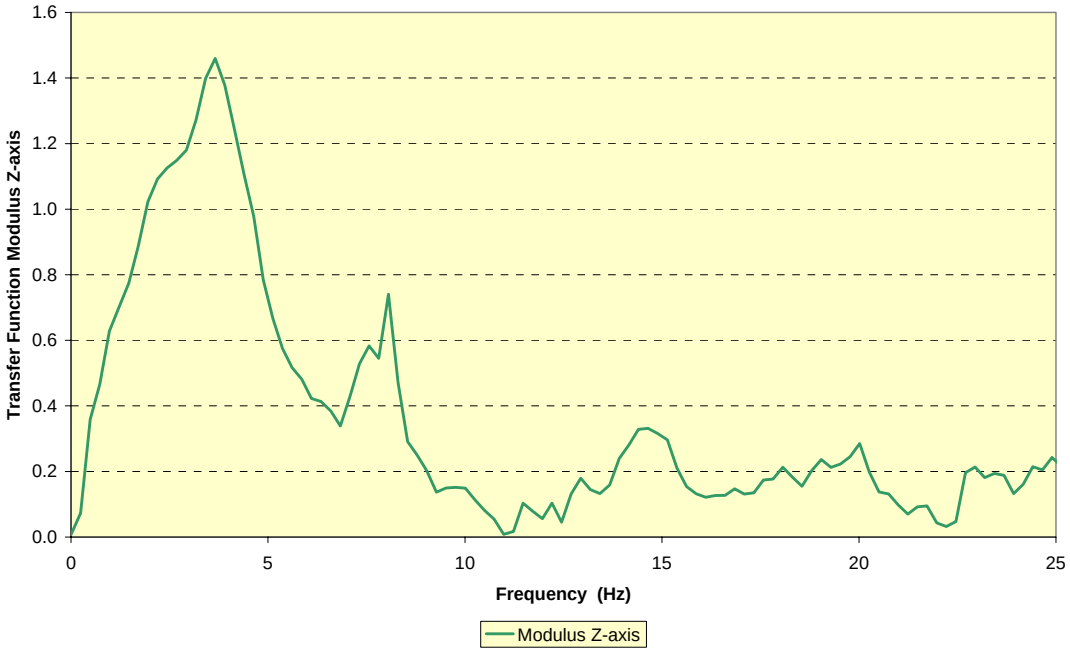

Figure A1.2.8 Thwaites 3-tonne articulated site dumper:- seat transfer function – Magnitude – whilst undertaking spoil removal (shuttle dumping)

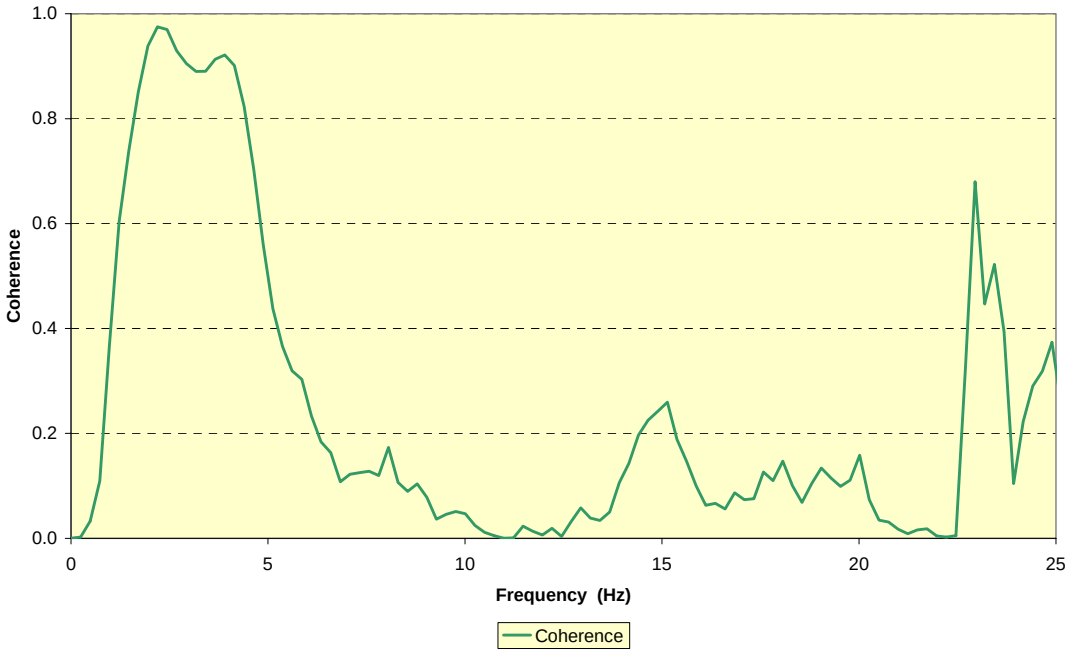

Figure A1.2.9 Thwaites 3-tonne articulated site dumper:- seat transfer function – Coherence – whilst undertaking spoil removal (shuttle dumping)

A1.2.3 Thwaites 3-tonne Articulated Site Dumper: WBV Data:- Soil Transport

Larson Davis HVM100	SN:00385	Day	Month	Year
Location:	***Floor***	***21***	***Jul***	***4***
Machine:	Site dumper Thwaites 7000			
Reg No:			Start time:	14:37
Task:	Soil Transport			
Place:	Diss			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
00:23	**6.3**	**9.3**	**8.2**	**13.9**
8-hr est tot	*13.6*	*19.8*	*17.5*	*29.7*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.63	***0.91***	***0.85***	***1.39***

Estimated values	**VDV**	**rms/A8**
Time to EAV (hr):	0.4	2.4
Time to ELV (hr):	10.2	12.7

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
4.10	7.25	6.30	7.51

Larson Davis HVM100	SN:00386	Day	Month	Year
Location:	***Seat***	***21***	***Jul***	***4***
Machine:	Site Dumper Thwaites 7000			
Reg No:			Start time:	14:37
Task:	Soil Transport			
Place:	Diss			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
00:23	**8.3**	**8.9**	**10.0**	**15.8**
8-hr est tot	*17.8*	*19.0*	*21.4*	*33.7*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.83	***0.91***	***0.96***	***1.56***

Estimated values	**VDV**	**rms/A8**
Time to EAV (hr):	0.3	2.2
Time to ELV (hr):	7.5	11.6

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
6.66	6.93	8.34	8.95

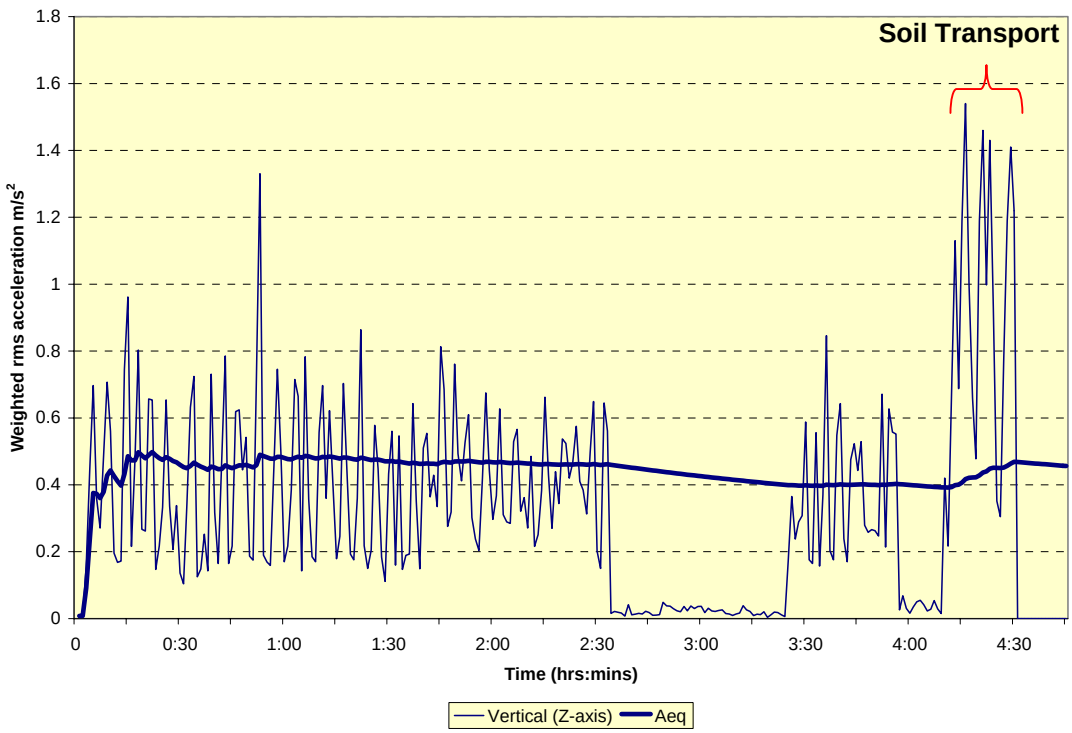

Figure A1.2.10 Thwaites 3-tonne articulated site dumper:- time history of weighted 1-minute rms seat accelerations (Z-axis) and equivalent continuous rms acceleration (Aeq) – entire measurement period

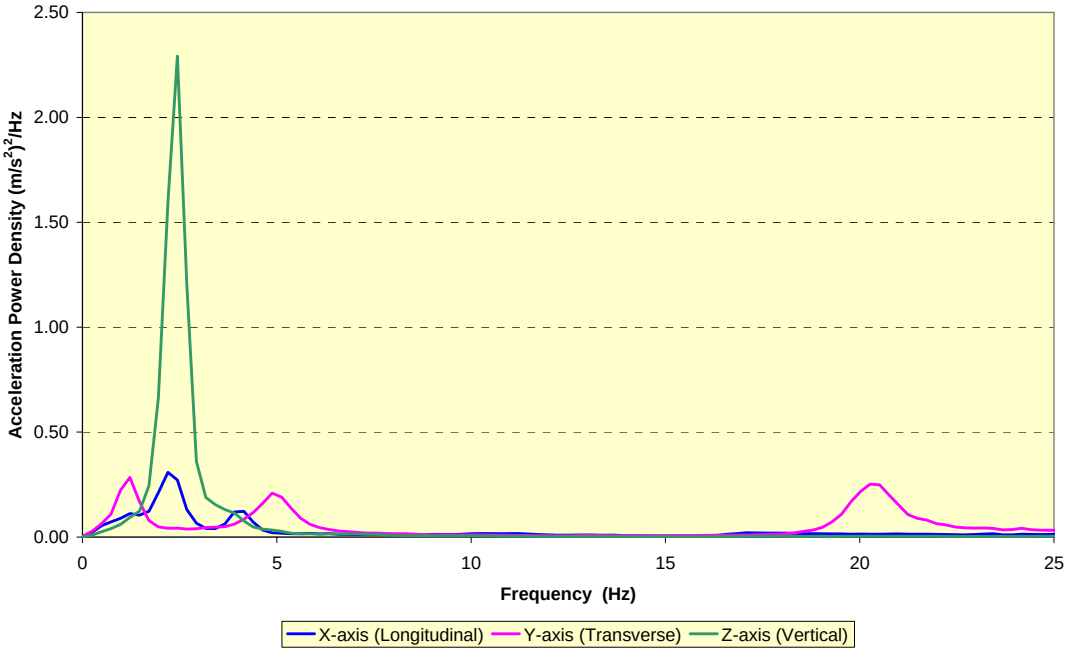

Figure A1.2.11 Thwaites 3-tonne articulated site dumper:- acceleration power spectral density (seat) – soil transport along farm track

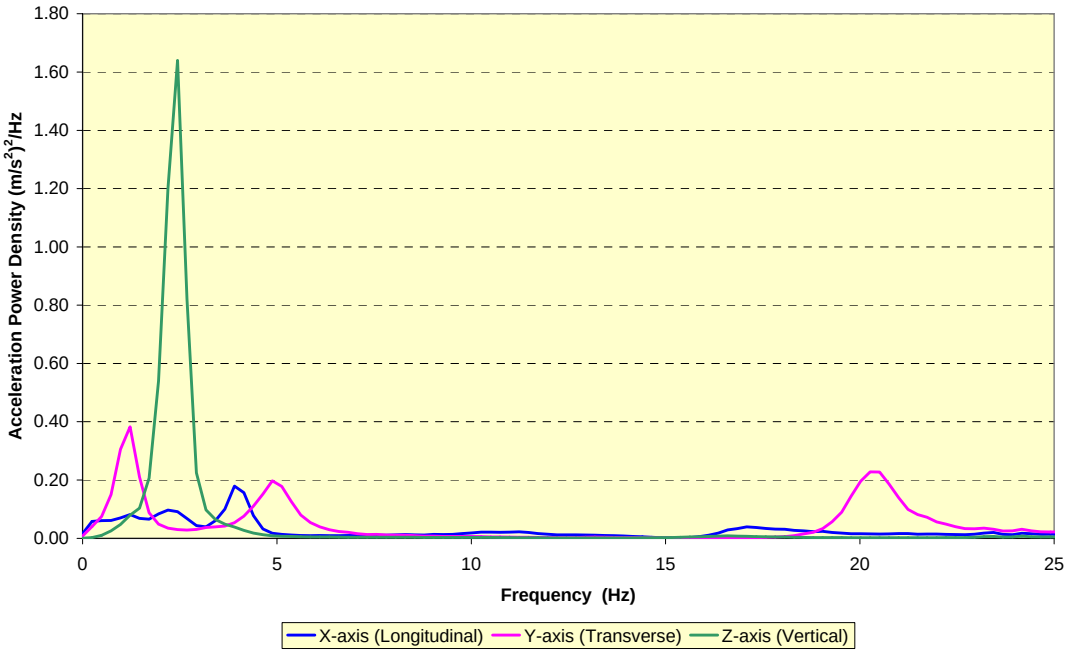

Figure A1.2.12 Thwaites 3-tonne articulated site dumper:- acceleration power spectral density (floor) – soil transport along farm track

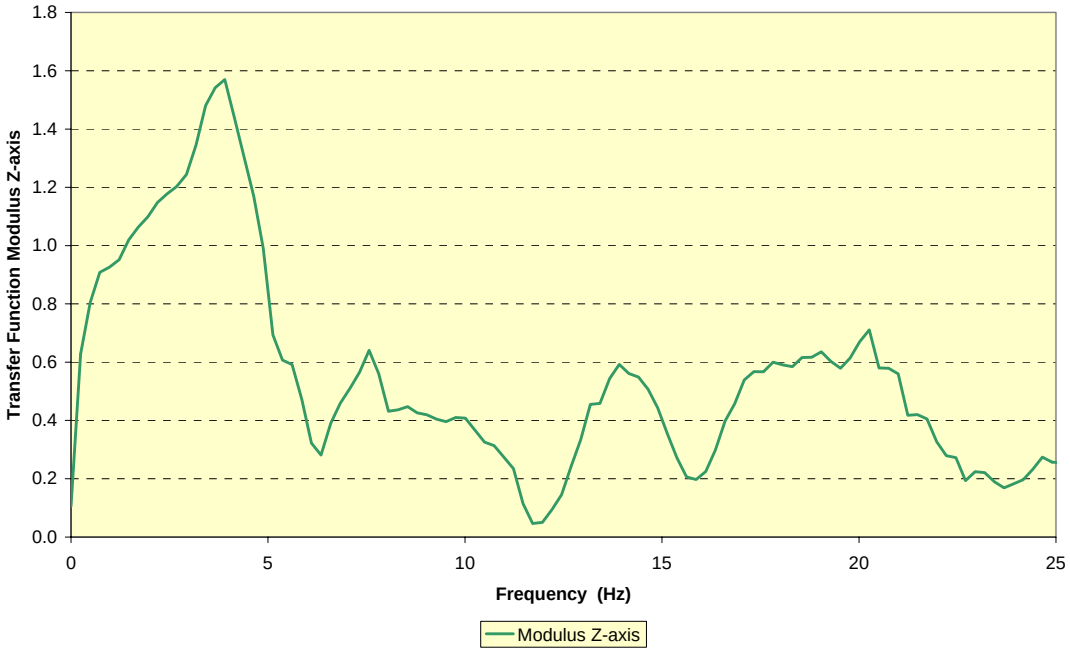

Figure A1.2.13 Thwaites 3-tonne articulated site dumper:- seat transfer function – Magnitude – whilst undertaking soil transport along farm track

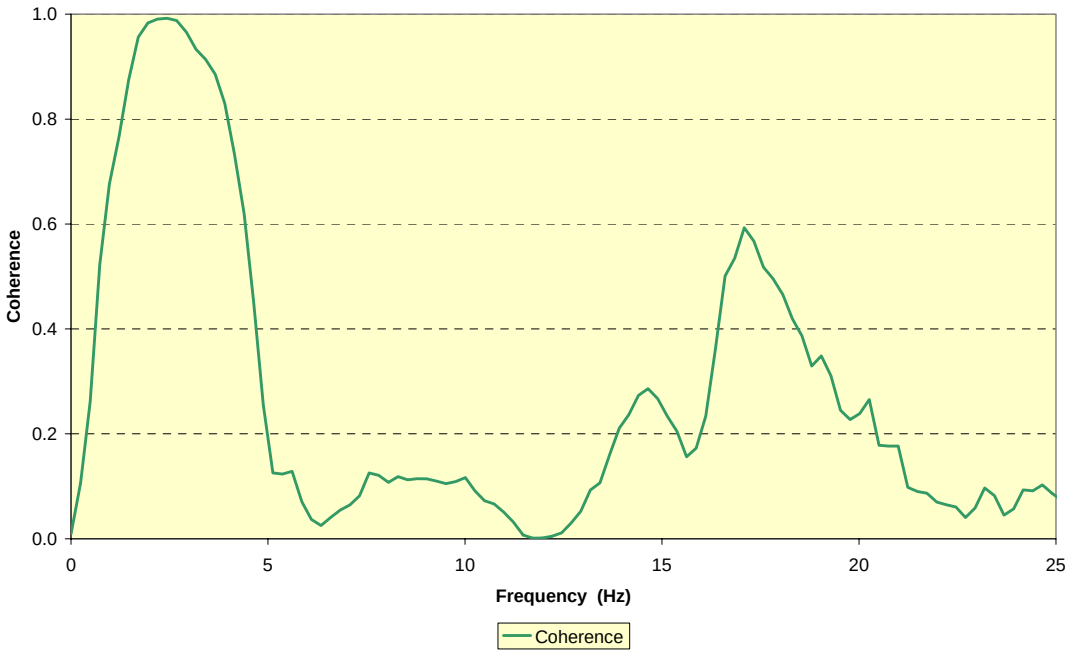

Figure A1.2.14 Thwaites 3-tonne articulated site dumper:- seat transfer function – Coherence – whilst undertaking soil transport along farm track

Appendix 1.3: Machine No.3 – Caterpillar D250E Articulated Dump Truck

A1.3.1 Operational Details

Date: Thurs 9th September 2004

Location: Horton Landfill Site
Small Dole, nr Henfield
West Sussex

Machine Make: Caterpillar Articulated Dump Truck
Model: D250E
Nominal Capacity: 25 tonnes
Built: 1996 (Relatively good mechanical condition
But relatively well through it 10-15 year working life)

Operator's name: Glen - experienced, considerate operator
Many years experience upon articulated dump trucks
Weight: 71.3 kg
Working for: P J Brown under subcontract to H Brett & Son

Tyre size(s): 23.5 x 25 Michelin on all (3) axles
Tyre pressure: 50-60 PSI (Tyre pressures were unable to be checked but deemed to be in the region of 50-60 PSI. All tyre deflections looked appropriate during the operating of the machine and therefore were not deemed to be either over or under inflated.)

Vehicle Suspension: Front axle of 3-axle machine supported on air-over-oil hydraulic rams to give front axle suspension. Rear suspension system is a tandem-axle (4-wheel-drive) walking beam bogie with Y-beam from each axle to a forward, central pivot point upon the chassis: a Panhard rod provides lateral location of each axle. Rubber/steel spring washer-type units provide vertical compliance where each axle attaches to the walking beam bogie. Suspension system gives approximately 50 – 75 mm suspension movement at each wheel, but considerably more articulation to follow ground contours.

Seat Suspension: Z-axis scissor-type air spring & hydraulic damper suspension: no suspension in X or Y-axes. Caterpillar own label (possibly Sears or KAB). Seat offset 0.6 m left of machine centreline.

WBV Instrumentation:
Seat:- SRI PCB seat pad plus operator seat presence switch
Floor:- SRI Floor Box No.3 attached to seat mounting
Both pieces of instrumentation feeding through Larson Davis Human Vibration Meters (LD 215 – Floor) & (LD 272 – Seat) and recording directly to Teac DR-C2 PC-card recorder.

Site Operation:- Machine hauling wet clay / cement kiln dust from 360° excavator, excavating a leachate storage lagoon on landfill site. Machine backs into lagoon area and is filled by 30 tonne 360° excavator. Subsequently hauls spoil along well-maintained haul road, (maintained by on-site bull-dozer) and tips at tipping area some 600 m away: making a 1.2 km round trip. Machine loading is very rapid (2-3 mins). Approximately 5 bucketfuls from the 360° excavator are required to load the dump truck, the ADT being of nominal 25 tonnes capacity. In general, cycle time (loading-transport laden-tipping-return unladen) appeared to be approx. 8 minutes.

Operational Comments:-

- Vehicle travelling on relatively smooth haul roads (maintained by on-site bulldozer), albeit with relatively large undulations, some rutting and some severe changes of direction and slope. Driver commented that haul road condition on-site was good compared to many sites he had used articulated dump trucks upon. Nonetheless, forward speed was limited by his selection of machine operating gear to 10 mph (16 km/h) on flatter sections of road, due to the level of WBV experienced. Machine slowed down further for substantial changes in slope and changes in direction.
- Little vibration is transferred to the articulated dump truck (ADT) during loading operation. Virtually all operator WBV is encountered during transport, especially when unladen.
- Operator attempts to stabilise himself against machine pitching and vertical motion of seat by holding on to window ledge of cab during machine motion.
- Machine has ½ tank of fuel. Apparently, due to size of fuel tank, ride unladen is improved when fuel tank is full.
- Throughout the morning's operation only one dump truck was used on-site and therefore it was not been delayed at any time waiting for other machines to be filled. However there were a number of general delays & breaks, during the 1-1½ hour operating period (see below).

Figure A1.3.1 Caterpillar D250E 25-tonne articulated dump truck at work on-site

Operational Record:-

Recording started: **08:27 hrs** **Duration:-** **1:33 hrs**
Recording stopped: **10:00 hrs**

Action started:- **08:36 hrs** **Data Analysis Period:- 0:01 – 1:33 hrs**
Action stopped:- **10:00 hrs** **Data Duration:- 1:33 hrs**

Time (hrs:mins)	Duration (hrs:mins)	Activity : Comments
8:30	**0:03**	Machine hauling wet clay / cement kiln dust from 360° excavator, excavating storage lagoon on landfill site. Machine stationary, awaiting loading.
8:36	**0:09**	Loading commences. Machine has been inactive in loading site from 08.30-08.36 hrs
8:38	**0:11**	Dump truck starts to leave loading area and moves along haul road.
8:45	**0:18**	Dump truck returning along haul road from tipping site.
8:48	**0:21**	Machine being loaded
8:49	**0:22**	Machine leaves loading area
8:53	**0:26**	Machine returning from dumping area along haul road
8:57	**0:30**	Machine leaves loading area
9:08	**0:41**	Truck returning from dumping area obviously been delayed by some external factors. Operator on phone, travelling at slightly more sedate pace returning to loading area
9:10	**0:43**	Loading commences
9:12	**0:45**	Loading complete, dump truck leaves loading area
9:16	**0:49**	Truck returning on haul road from dumping area
9:18	**0:51**	Loading commenced
9:20	**0:53**	Loading completed but machine remaining in loading area
9:25	**0:58**	Machines loaded but still stationary in loading area driver has remained in seat. As far as I am aware, driver has remained in seat throughout entire morning's operation
9:31	**1:04**	Leaves loading area
9:36	**1:09**	Truck returning to loading area
9:37	**1:10**	Loading commenced
9:39	**1:12**	Loading complete, machine leaving loading area
9:44	**1:17**	Machine returning along haul road
9:45	**1:18**	Loading commenced
9:47	**1:20**	Machine leaves loading area
9:52	**1:25**	Dump truck returns to loading area
9:53	**1:26**	Loading commenced
9:55	**1:28**	Loading complete, machine leaves loading area
10:00	**1:33**	Machine returning along haul road. Operation complete: recording stopped.

A1.3.2 Caterpillar 25-tonne Articulated Dump Truck Whole-Body Vibration Data

Larson Davis HVM100	SN:00215	Day	Month	Year
Location:	***Floor***	***9***	***9***	***2004***
Machine:	Caterpillar 25 tonne Articulated Dump Truck			
Model No:	D250E		Start time:	08:27
Task:	Soil Transport			
Place:	Henfield, Sussex			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
01:35	**9.7**	**11.0**	**11.7**	**18.7**
8-hr est tot	*14.5*	*16.4*	*17.5*	*28.1*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.61	***0.73***	***0.64***	***1.14***

Estimated values	**VDV**	**rms/A(8)**
Time to EAV (hr):	0.6	3.8
Time to ELV (hr):	16.4	20.1

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
6.94	6.23	18.70	18.80

Larson Davis HVM100	SN:00272	Day	Month	Year
Location:	***Seat***	***9***	***9***	***2004***
Machine:	Caterpillar 25 tonne Articulated Dump Truck			
Model No:	D250E		Start time:	08:27
Task:	Soil Transport			
Place:	Henfield, Sussex			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
01:35	**11.8**	**13.9**	**9.5**	**20.6**
8-hr est tot	*17.7*	*20.9*	*14.2*	*30.9*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.78	***0.92***	***0.58***	***1.34***

Estimated values	**VDV**	**rms/A(8)**
Time to EAV (hr):	0.3	2.3
Time to ELV (hr):	8.2	12.4

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
7.14	11.24	7.65	11.70

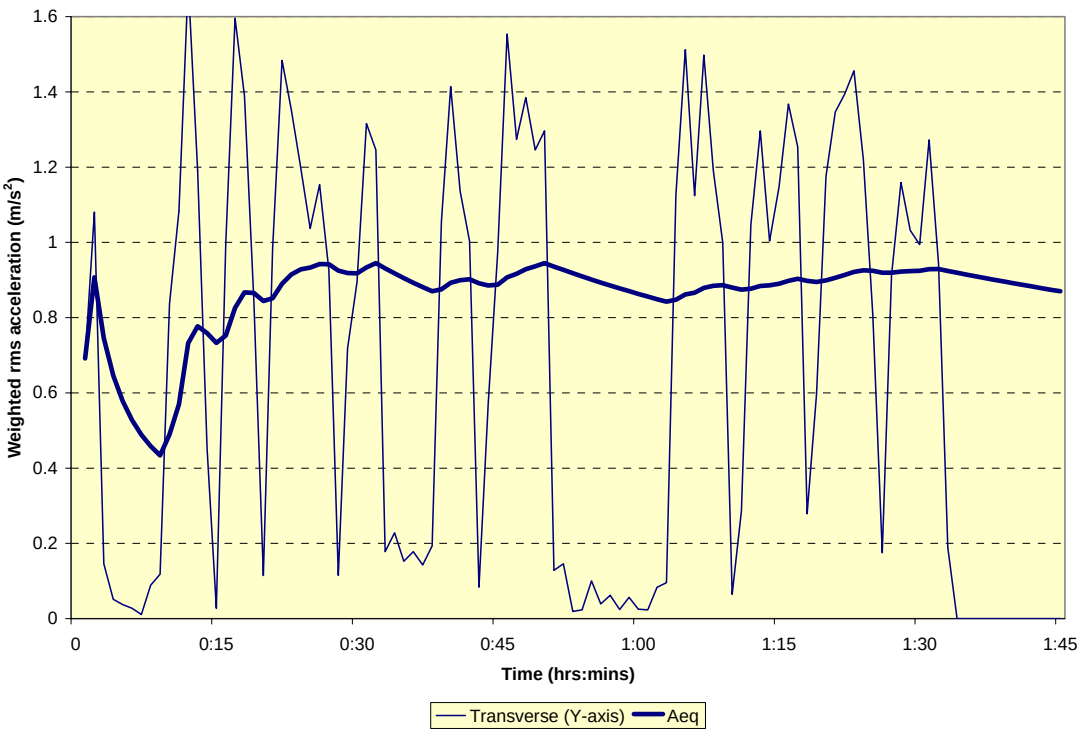

Figure A1.3.2 Caterpillar 25-tonne Articulated Dump Truck:- time history of weighted 1-minute rms seat accelerations (Y-axis) and equivalent continuous rms acceleration (Aeq)

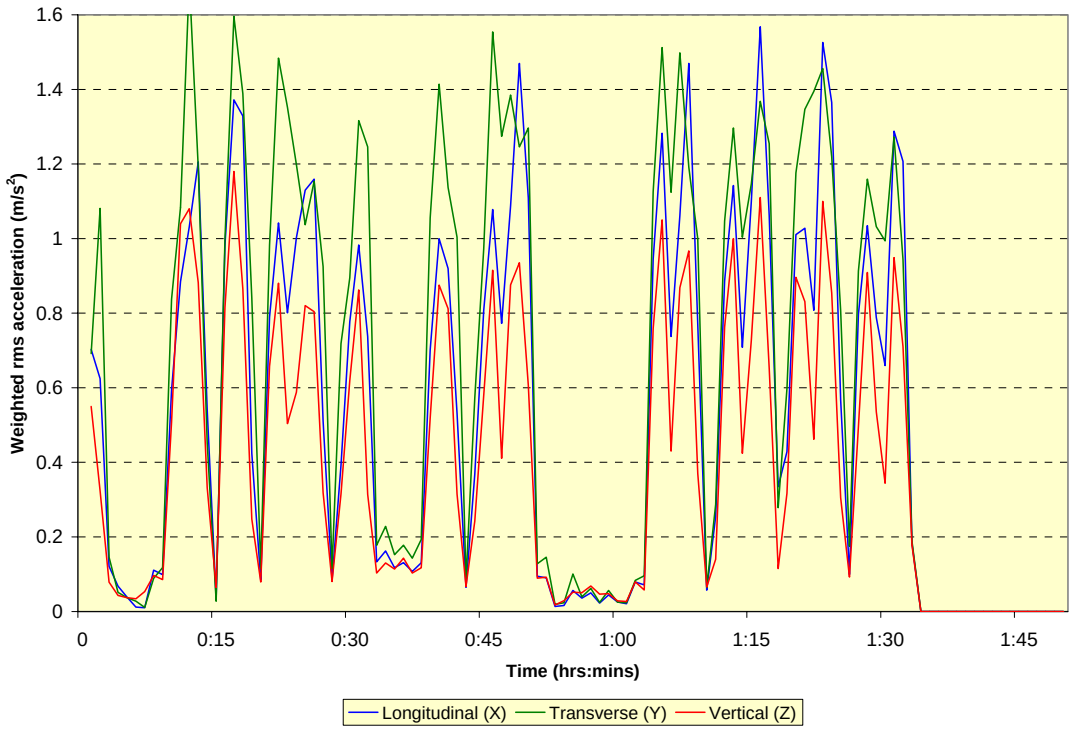

Figure A1.3.3 Caterpillar Articulated Dump Truck:- time histories of weighted 1-minute rms seat accelerations (X, Y and Z-axes)

Figure A1.3.4 Caterpillar Articulated Dump Truck:- time histories of weighted 1-minute peak seat accelerations (X, Y and Z-axes)

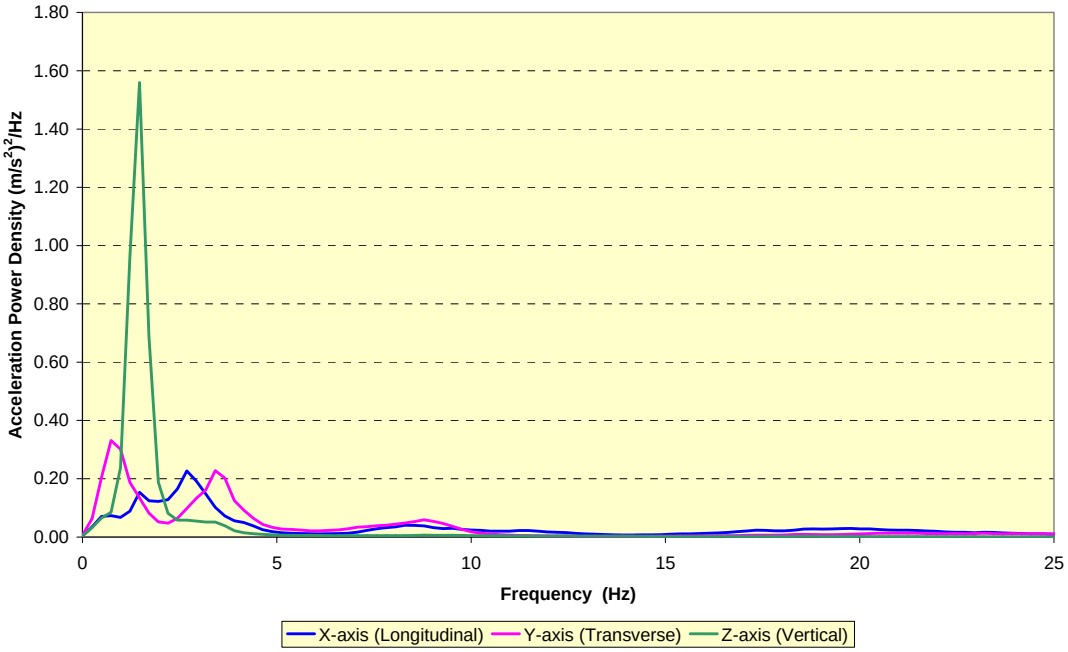

Figure A1.3.5 Caterpillar Articulated Dump Truck:- acceleration power spectral density (seat)

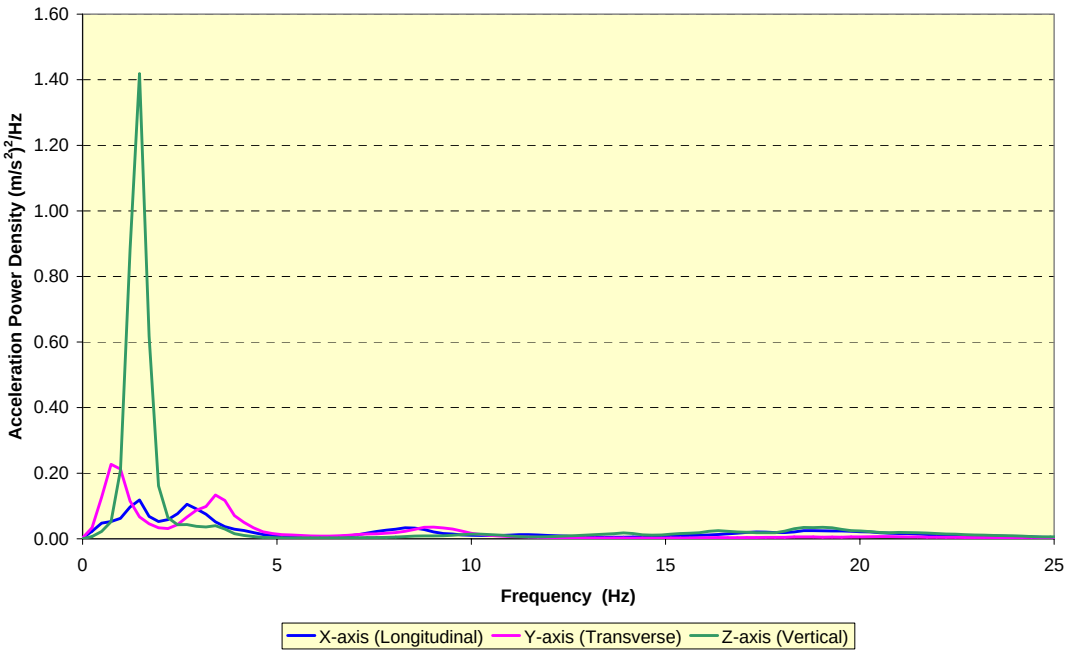

Figure A1.3.6 Caterpillar Articulated Dump Truck:- acceleration power spectral density (floor)

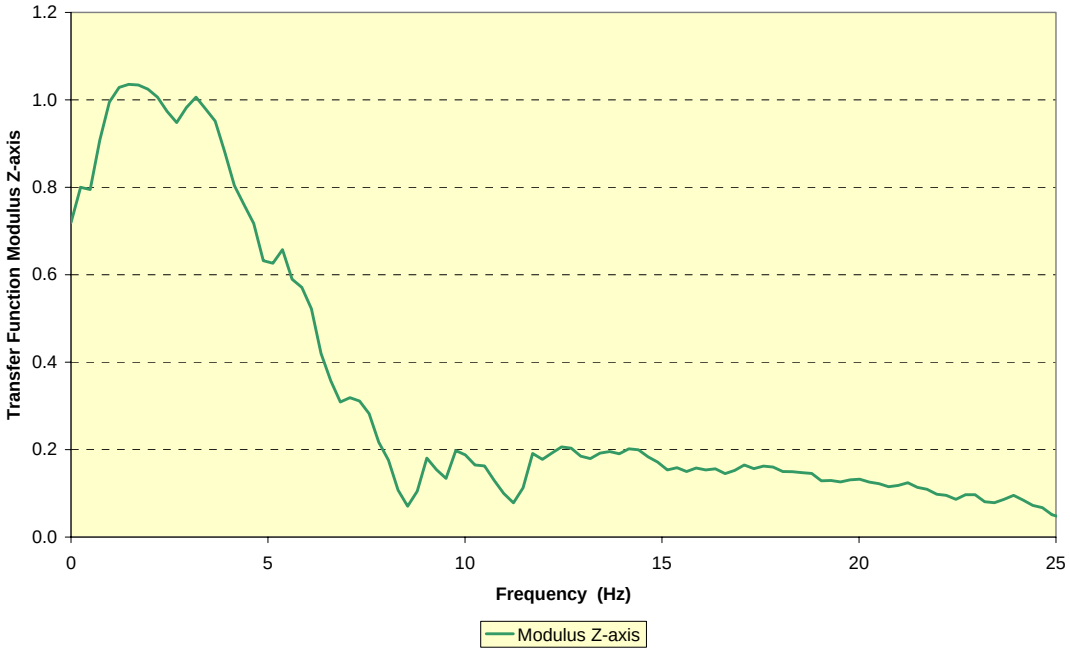

Figure A1.3.7 Caterpillar Articulated Dump Truck:- seat transfer function – Magnitude

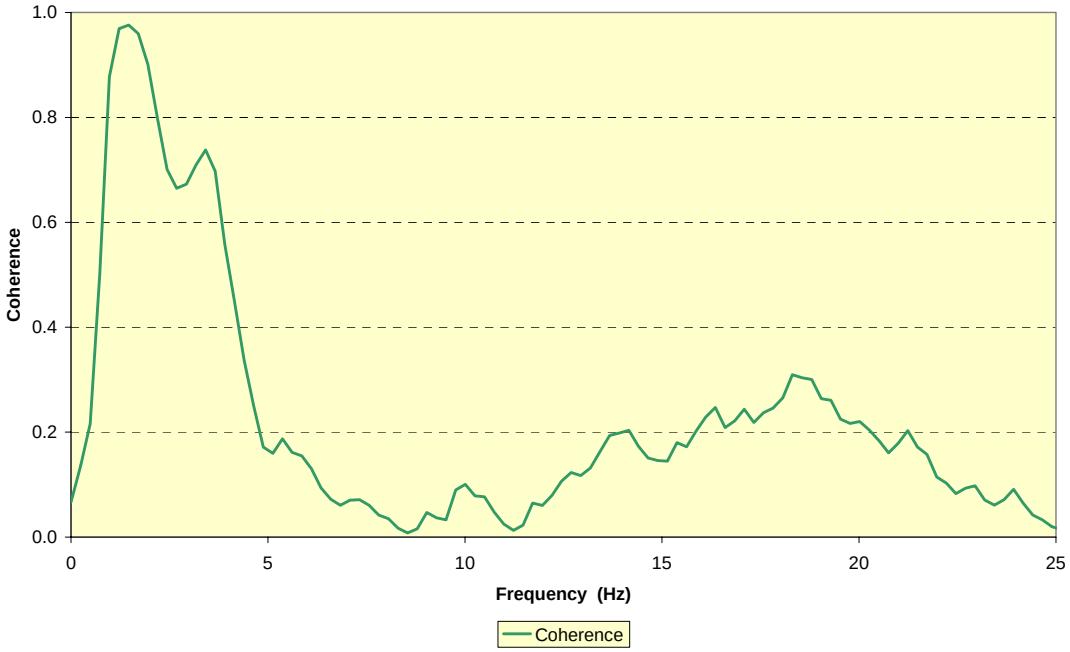

Figure A1.3.8 Caterpillar Articulated Dump Truck:- seat transfer function – Coherence

Appendix 1.4: Machine No.4 - Komatsu D65EX-12 Bulldozer

A1.4.1 Operational Details

Date: Thurs 9th September 2004

Location: Horton Landfill Site
Small Dole, Nr Henfield
West Sussex

Machine Make: Komatsu
Model: D65EX – 12
Age: 1998
Mass: 18480 kg
Serial no: 62362
Engine power: 142 kW
Operating hours: 8600 hrs

- Machine on hire from Serle Plant, following breakdown of newer machine which was originally to be targeted, is in moderate operational condition, with the exception of the operator's seat.

Track width (Centre-Centre):- 1.9 m
Grouser width: 660mm
Track system:- rear drive sprocket: front idler roller
Track gauge:- 212mm
No of Bottom Idlers:- 7
Bottom Idler Spacing:- 295mm
Track length (in ground contact) ≈ 3.0m

Operator's name: Andy Chiswick:- Experienced, conscientious & characteristically 'steady'
Weight: 87.3 kg

Tyre pressure: N/A

Vehicle Suspension: No suspension but and no evidence of iso-mounted cab. Cab structure incorporates ROPS

Driver's Suspension Seat:- KAB Model No. 411 scissor-type, mechanical spring and damper z-axis suspension. Seat upholstery in acceptable condition, but the suspension system is very worn & also set very firmly, giving little vibration isolation in the vertical axis. Additionally, the seat upper, which has tilt adjustments, is poorly attached to the seat suspension system and is capable of a degree of fore and aft pitch. A seat belt is fitted to the seat but is not used by the operator.

WBV Instrumentation:

Seat:- SRI ICP-type PCB 356B40 in seat pad plus operator seat presence switch
Floor:- SRI Floor Box No.3 attached to seat mounting
Both pieces of instrumentation feeding through Larson Davis Human Vibration Meters (LD 215 – Floor) & (LD 272 – Seat) and recording directly to **Teac** DR-C2 PC-card recorder.

Site Operation:- Undertaking extension of existing landfill site in conjunction with other soil excavation & transportation machines. Activities include haul road maintenance (small proportion) and moving / levelling soil deposited by articulated dump trucks (majority of activity recorded). The latter involved pushing clay from compacted stockpile into previously used reservoir / lagoon area which was being filled. Material was a relatively heavy soil / clay mixture and appeared to be of moist-firm consistency, giving good traction but little track sinkage.

Operational Comments:-

- Operating conditions were sufficiently dry and firm to transfer some vibration from grousers into the machine.
- Dozer forward speed when loaded and pushing was approx. 3mph or perhaps even less on occasion; speed in reverse when returning for a second push, approximately 4 mph.
- Operator was visibly vibrated by passage of grousers and track links over sprockets during push cycle. Could see operator's shoulders moving both longitudinally and slightly vertically despite very slow forward speed of the machine, probably about 2-3mph. On return path at higher speed, probably 4-5mph, it was possible to feel vibration from the tracks actually through the ground adjoining the working area.
- Small amount of vibration during work is due to occasional impacts originating from blade-soil contact, but the majority of vibration arises from the passage of track segments across the idler rollers and the drive sprocket.

Operational Record:-

Recording started: **13:42 hrs** **Duration:-** **2:05 hrs**
Recording stopped: **15:47 hrs**
Analysis Period:- **0:06 hrs – 1:55 hrs** **Analysis Duration:-** **1:50 hrs:mins**

Time (hrs:mins)	Duration (hrs:mins)	Activity : Comments
13:42 – 13:43	**0:00 – 0:01**	Recording begins. Dozer currently stationary
13.49	**0:07**	Dozer begins short travel into lagoon area. Begins levelling haul road section within lagoon area and back-filling trench over drainage pipes. Trackway conditions on which dozer running on are relatively hard, sending quite substantial vibrations into dozer main frame as grousers contact surface.
13.54	**0:12**	Travel along hard site road back up to other working area
13.57	**0:15**	Reaches working area and begins dozing (levelling soil transported by dump trucks)
14.08	**0:26**	Return cycle begins
14.08.45	**0:26:45**	Push cycle begins
14.18	**0:36**	Dozer work going on as previously described, filling in old lagoon.
14.44	**1:02**	Site levelling and dozing continuing as previously described
15.40	**1:58**	Dozing operation completed due to current area being cleared and levelled off
15.42	**2:00**	Machine tracks away from lagoon site back to bowser area, along haul road in preparation for instrumentation to be removed and also refilling with diesel.
15.47	**2:05**	Operation stopped

Figure A1.4.1 Komatsu D65EX-12 bulldozer at work on-site

A1.4.2 Komatsu Bulldozer Whole-Body Vibration Data

Larson Davis HVM100	SN:00215	Day	Month	Year
Location:	***Floor***	***9***	***9***	***4***
Machine:	Komatsu Bulldozer			
Model No:	D65EX-12		Start time:	13:48
Task:	Levelling soil / backfilling			
Place:	Horton Landfill Site, Henfield, Sussex			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
01:50	**8.0**	**6.1**	**17.7**	**20.3**
8-hr est tot	*11.5*	*8.8*	*25.5*	*29.4*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.48	***0.44***	***1.25***	***1.40***

Estimated values	**VDV**	**rms/A(8)**
Time to EAV (hr):	0.1	1.3
Time to ELV (hr):	3.7	6.8

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
5.05	5.67	20.70	20.60

Larson Davis HVM100	SN:00272	Day	Month	Year
Location:	***Seat***	***9***	***9***	***4***
Machine:	Komatsu Bulldozer			
Model No:	D65EX-12		Start time:	13:48
Task:	Levelling soil / backfilling			
Place:	Horton Landfill Site, Henfield, Sussex			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
01:50	**10.4**	**7.9**	**18.0**	**22.2**
8-hr est tot	*15.0*	*11.4*	*26.0*	*32.1*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.63	***0.55***	***1.45***	***1.67***

Estimated values	**VDV**	**rms/A(8)**
Time to EAV (hr):	0.1	1.0
Time to ELV (hr):	3.4	5.0

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
7.39	8.48	7.61	8.90

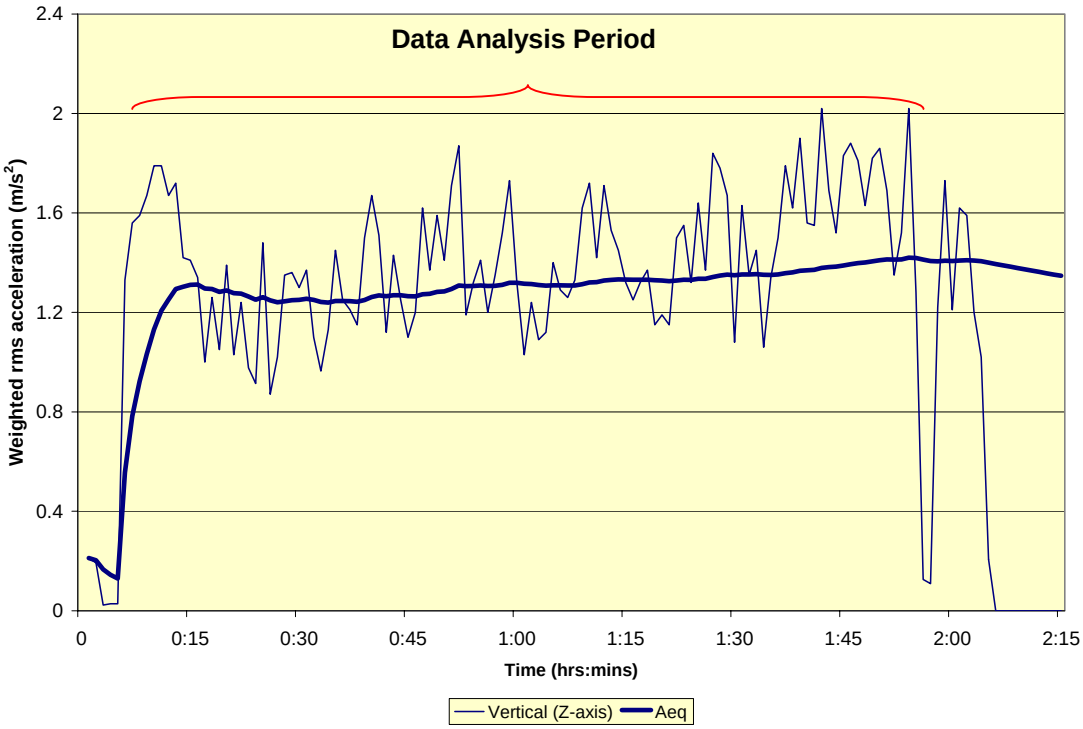

Figure A1.4.2 Komatsu Dozer:- time history of weighted 1-minute rms seat accelerations (Z-axis) and equivalent continuous rms acceleration (Aeq)

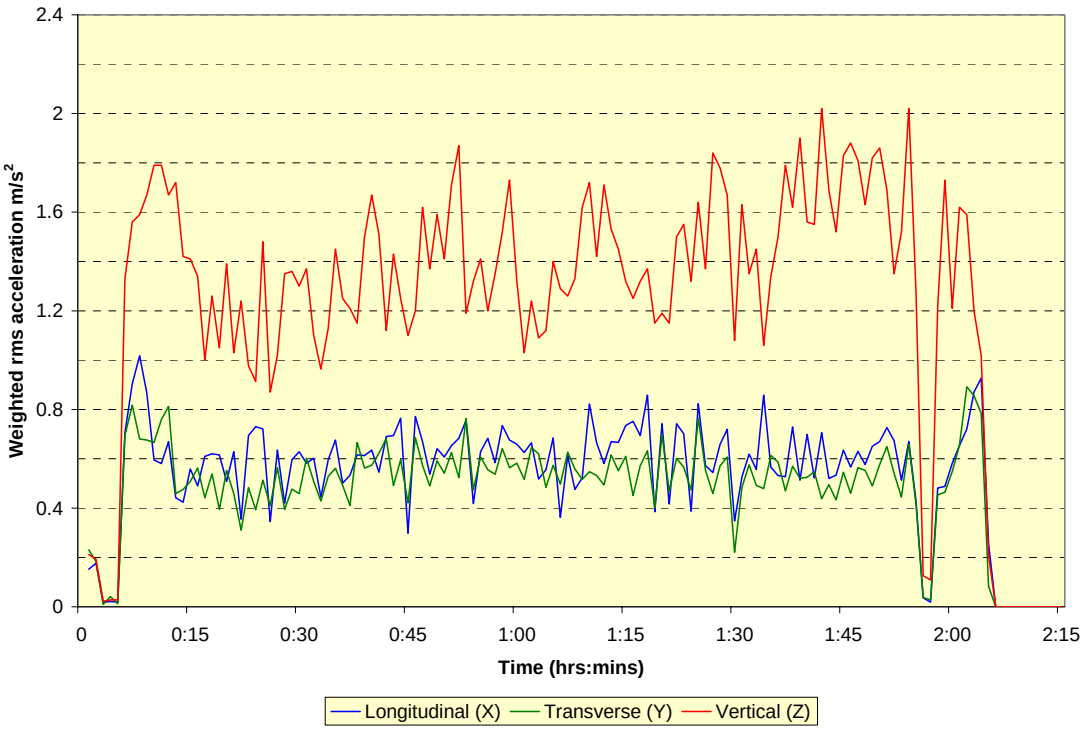

Figure A1.4.3 Komatsu Dozer:- time histories of weighted 1-minute rms seat accelerations (X, Y and Z-axes)

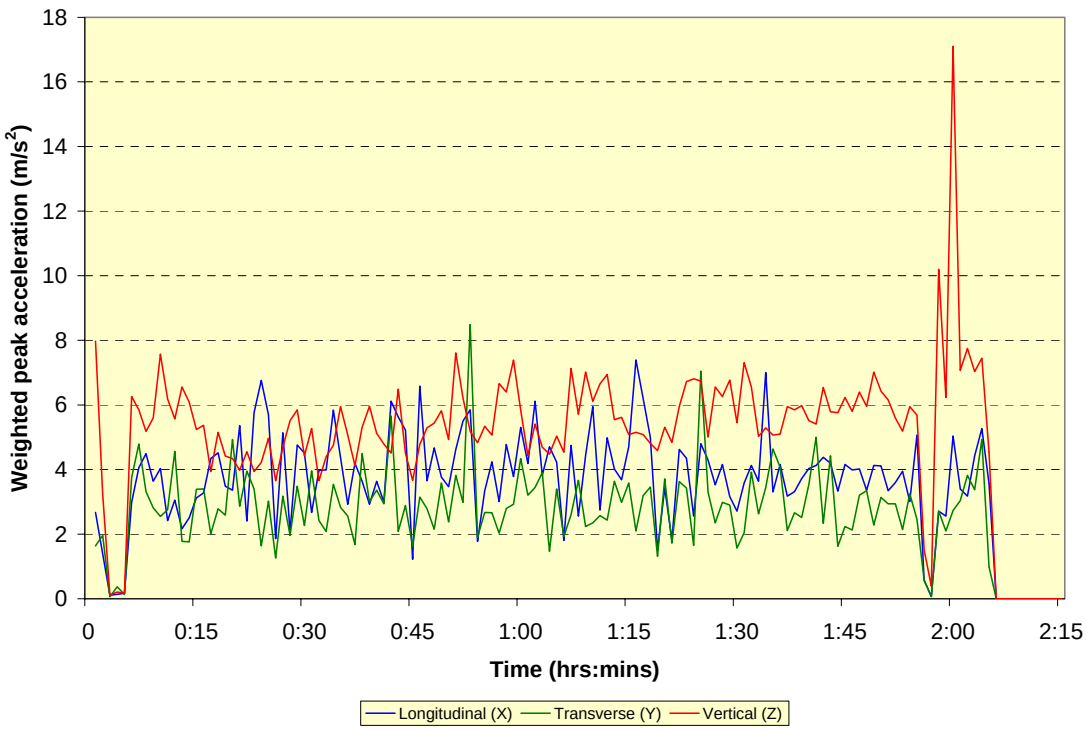

Figure A1.4.4 Komatsu Dozer:- time histories of weighted 1-minute peak seat accelerations (X, Y and Z-axes)

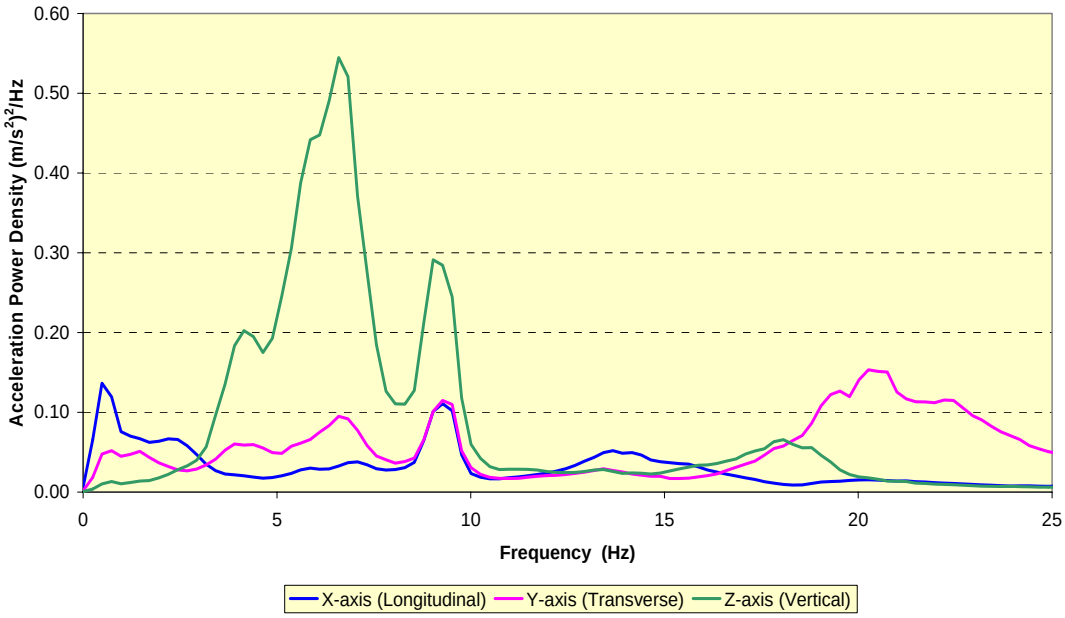

Figure A1.4.5 Komatsu Dozer:- acceleration power spectral density (seat)

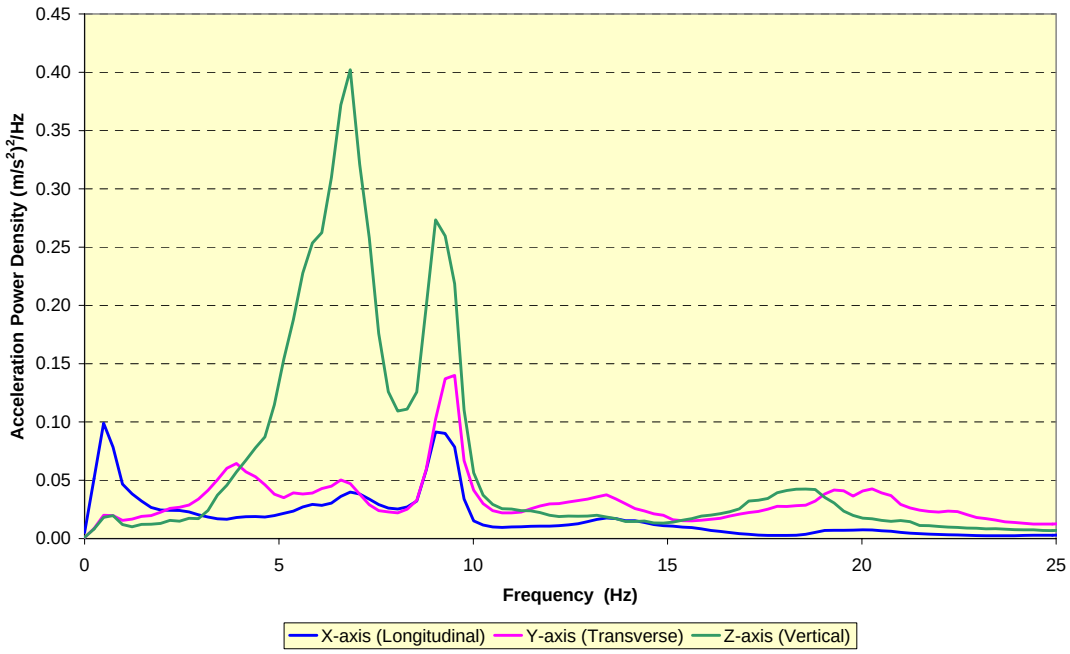

Figure A1.4.6 Komatsu Dozer:- acceleration power spectral density (floor)

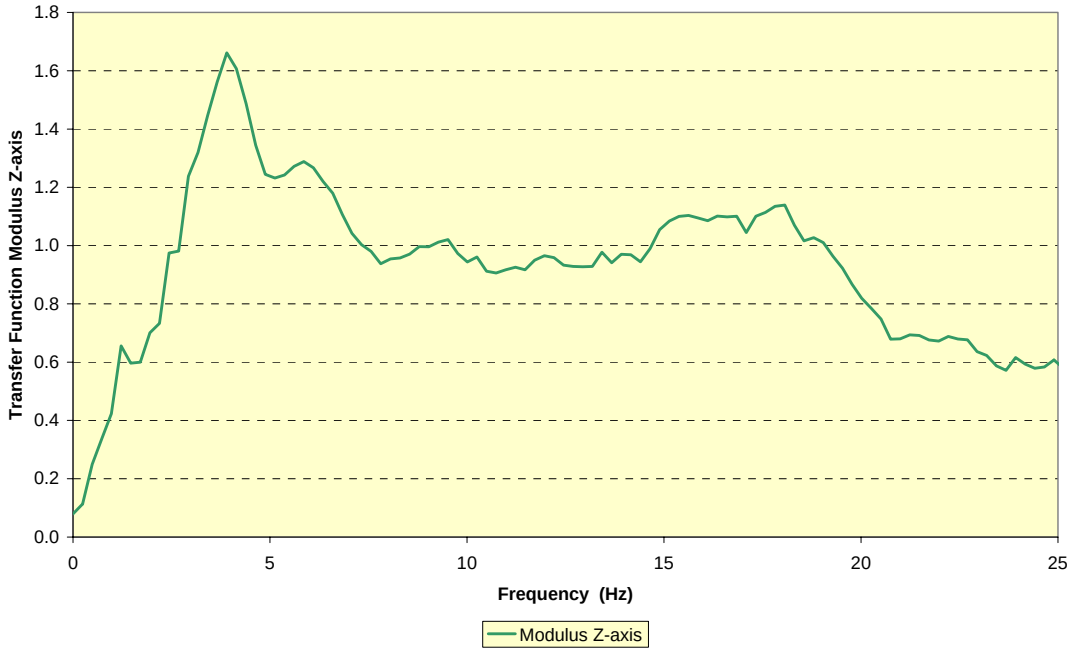

Figure A1.4.7 Komatsu Dozer:- seat transfer function – Magnitude

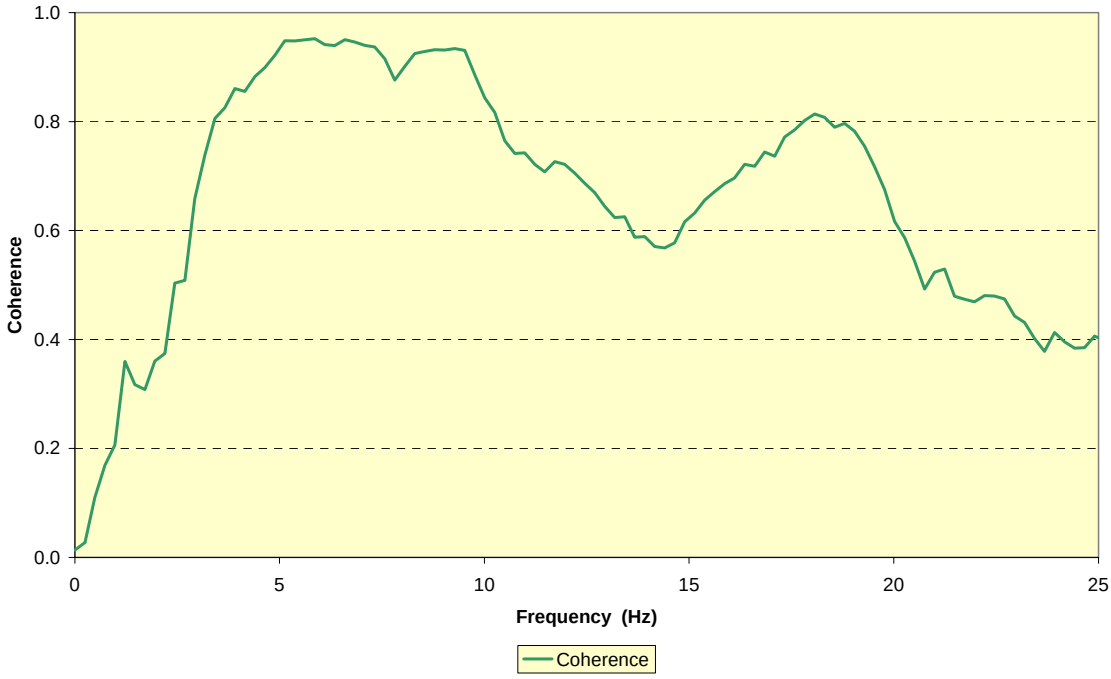

Figure A1.4.8 Komatsu Dozer:- seat transfer function – Coherence

Appendix 1.5: Machine No.5 – Liebherr R994 Face Shovel

A1.5.1 Operational Details

Date: Wednesday 22nd September 2004

Location: Lafarge Aggregates
Mountsorrel Quarry
Mountsorrel, Leicestershire.

Machine make: Liebherr
Model: R994 Litronic 360° Face Shovel
Age: 1998
Power: 728 kW
Mass: ≈ 225 tonnes
Serial number: 171-0256
Nominal bucket capacity: 25 tonnes (5 bucketfuls →80 tonne dump truck)
Approximate annual usage: 3400 hrs
Approximate age: 22,000 hrs
Condition: Moderate/Good, but aspects of operator station design show age (could benefit from improvement).

Track width (centre to centre): 4.9 m
Grouser width: 0.32 m
Number of Bottom idlers: 10
Bottom idler spacing: 4 @ 0.49 m; 4 @ 0.57 m, 3 @ 0.4 m

Track length (in ground contact): 6.5 m

Driver's name: Pete
Driver's experience level: High - 6 years on face shovels
Weight: ≈ 80 kg

Drivers seat:
Make:- KAB
Model:- 525 P
Type:- Z-axis mechanical spring and damper, scissor-type suspension.
- Two x/y electronic joysticks fitted to seat-mounted pods (suspended).
- Suspension in moderate/good condition and correctly-adjusted for driver's mass <u>but</u> seat upper showing considerable signs of wear.

Operator's cab: Due to large size of machine, cab design is more reminiscent of an office. Lots of space present, but poor ergonomics / bucket visibility.
- Necessary for operator to lean forward and look to right to obtain good view of bucket when digging at surface level.
- Apparently better view/more comfortable when working into a stockpile of decent height (dependent upon blasting procedure).
- Cab is iso-mounted and mounts have been replaced during m/c lifetime (6 yrs), but rear RH mount (of 6) apparently failed at time of measurement. Movement of cab structure relative to rest of the machine, evident.

WBV Instrumentation:
Seat:- SRI ICP-type PCB 356B40 in seat pad plus operator seat presence switch
Floor:- SRI Floor Box No.3 attached to seat mounting
Both pieces of instrumentation feeding through Larson Davis Human Vibration Meters (LD 215 – Floor) & (LD 272 – Seat) and recording directly to Teac DR-C2 PC-card recorder.

Operational Comments:-

- Considerable pitch & X-axis WBV present in-cab, especially when digging into stockpile/rock heap.
- Significant impact transmitted through machine structure if bucket slams shut.
- Considerable X and Z-axis acceleration generated when scraping/levelling quarry floor and scraping from lower parts of heap.
- 2 large (80-tonne capacity) rigid dump trucks (CAT 777) transport material away from machine. Cycle time ≈ 10 mins.

Operational Record:-

Time (hrs:mins)	Duration (hrs:mins)	Activity : Comments
08.31	**0:00**	Recording starts. Loading trucks - AJS in cab. - Few slight pauses for dump truck arrival. Otherwise continuous loading.
09.30	**0:59**	Breakfast/refuelling break
09.46	**1:15**	Levelling quarry floor and heaping rock pile
09.48	**1:17**	Levelling quarry floor and heaping rock pile
09.50	**1:19**	- Continuous loading of ≈90 tonne dump trucks - begins loading new truck every 10 mins
11.59	**3:28**	Tracking away from rock face to safety area, prior to blasting new material.
12.08	**3:37**	Tracking away from rock face to safety area,
12.09	**3:38**	Recording stopped

Data Analysis:-

The machine performed two specific activities during the measurement period:-

i) Loading 80 tonne capacity dump trucks at the quarry face
~ 1 hour before breakfast ……**Not analysed;**
~ 2:14 hours after breakfast. **1:14 to 3:27 hrs:- (Dataset (a))**

ii) Tracking away from the quarry face to a safety area, before blasting occurred.
~ 8-9 minutes **3:28 to 3:37 hrs:- (Dataset (b))**

Datasets (a) and (b) were analysed separately: the results are presented in Appendices A1.5.2 and A1.5.3 respectively, **but** the time-histories presented in Figures A1.5.2, A1.5.3, A1.5.4 and A1.5.9 depict the entire recording period.

Figure A1.5.1 Liebherr R994 face shovel – at rest and play

A1.5.2 Liebherr Face Shovel WBV Data:- Excavating / Loading Dump Trucks

Larson Davis HVM100	SN:00215	Day	Month	Year
Location:	***Floor***	***22***	***9***	***4***
Machine:	Liebherr Tracked Face Shovel			
Model No:	R994 Litronic		Start time:	09:46
Task:	Loading blasted granite			
Place:	Mountsorrel Quarry, Leics			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
02:14	**10.4**	**7.2**	**16.7**	**20.9**
8-hr est tot	*14.3*	*9.9*	*22.9*	*28.8*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.62	***0.40***	***0.72***	***1.02***

Estimated values	**VDV**	**rms/A(8)**
Time to EAV (hr):	0.2	3.9
Time to ELV (hr):	5.6	20.4

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
7.80	6.13	23.10	23.20

Larson Davis HVM100	SN:00272	Day	Month	Year
Location:	***Seat***	***22***	***9***	***4***
Machine:	Liebherr Tracked Face Shovel			
Model No:	R994 Litronic		Start time:	09:46
Task:	Loading blasted granite			
Place:	Mountsorrel Quarry, Leics			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
02:14	**12.6**	**8.9**	**11.2**	**19.1**
8-hr est tot	*17.4*	*12.3*	*15.4*	*26.3*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.74	***0.50***	***0.61***	***1.08***

Estimated values	**VDV**	**rms/A(8)**
Time to EAV (hr):	0.6	3.6
Time to ELV (hr):	17.1	19.2

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
8.41	7.49	34.50	34.40

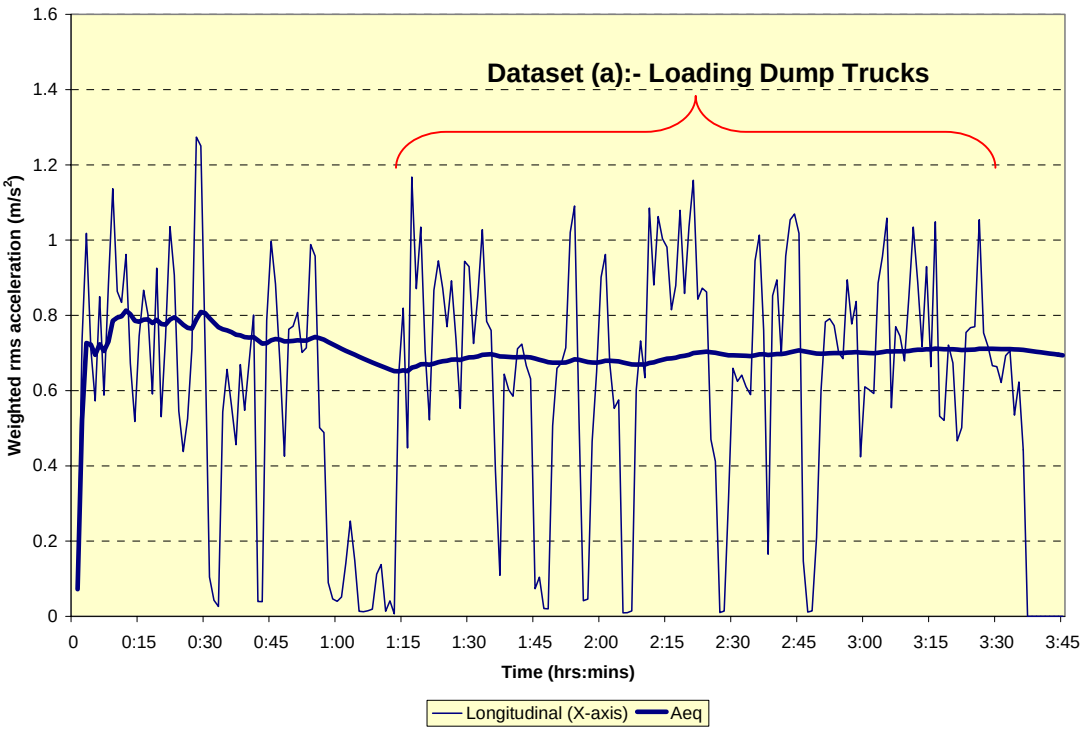

Figure A1.5.2 Liebherr Face Shovel:- time history of weighted 1-minute rms seat accelerations (X-axis) and equivalent continuous rms acceleration (Aeq) – entire recording period

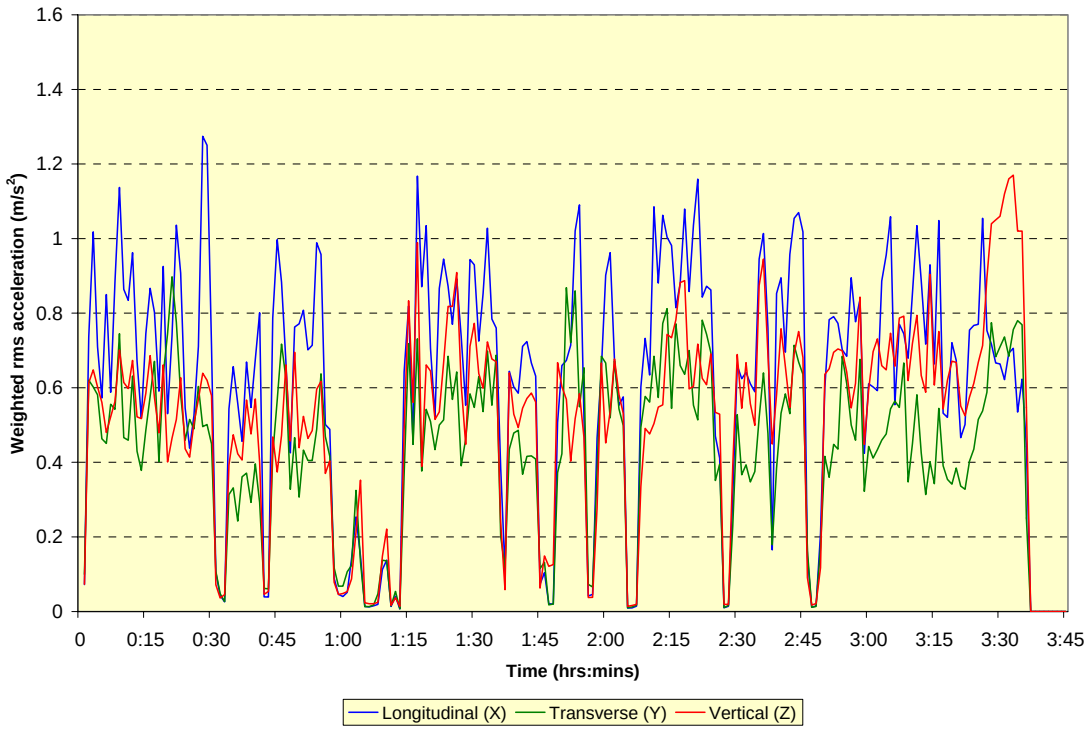

Figure A1.5.3 Liebherr Face Shovel:- time histories of weighted 1-minute rms seat accelerations (X, Y and Z-axes) – entire recording period

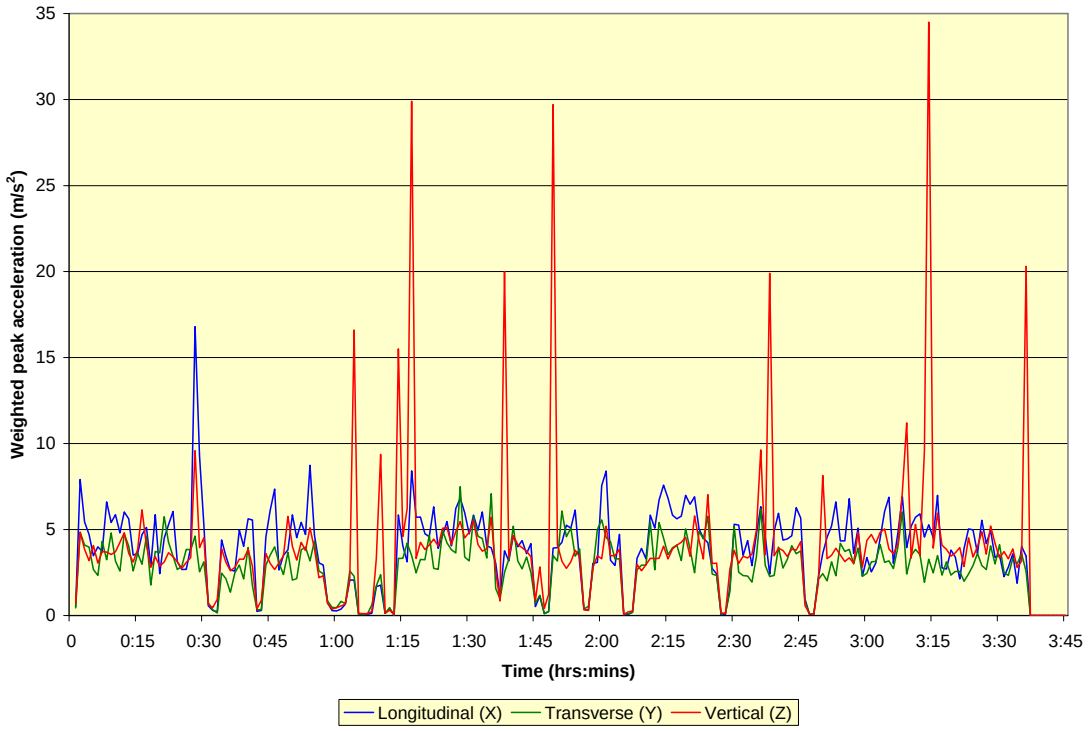

Figure A1.5.4 Liebherr Face Shovel:- time histories of weighted 1-minute peak seat accelerations (X, Y and Z-axes) – entire recording period

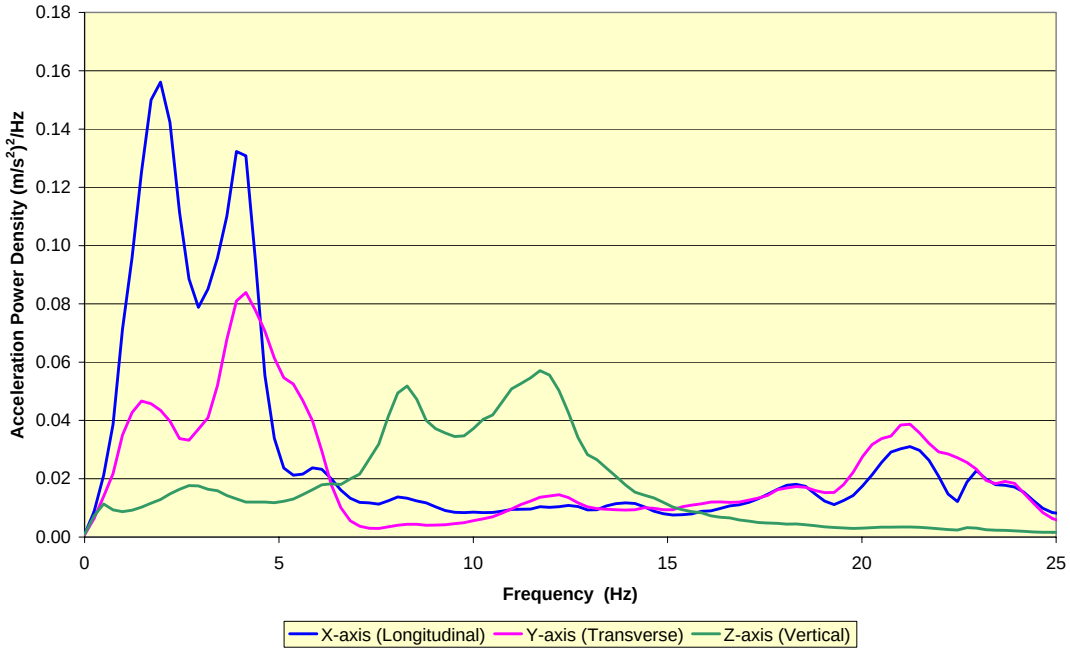

Figure A1.5.5 Liebherr Face Shovel:- acceleration power spectral density (seat) – whilst loading dump trucks

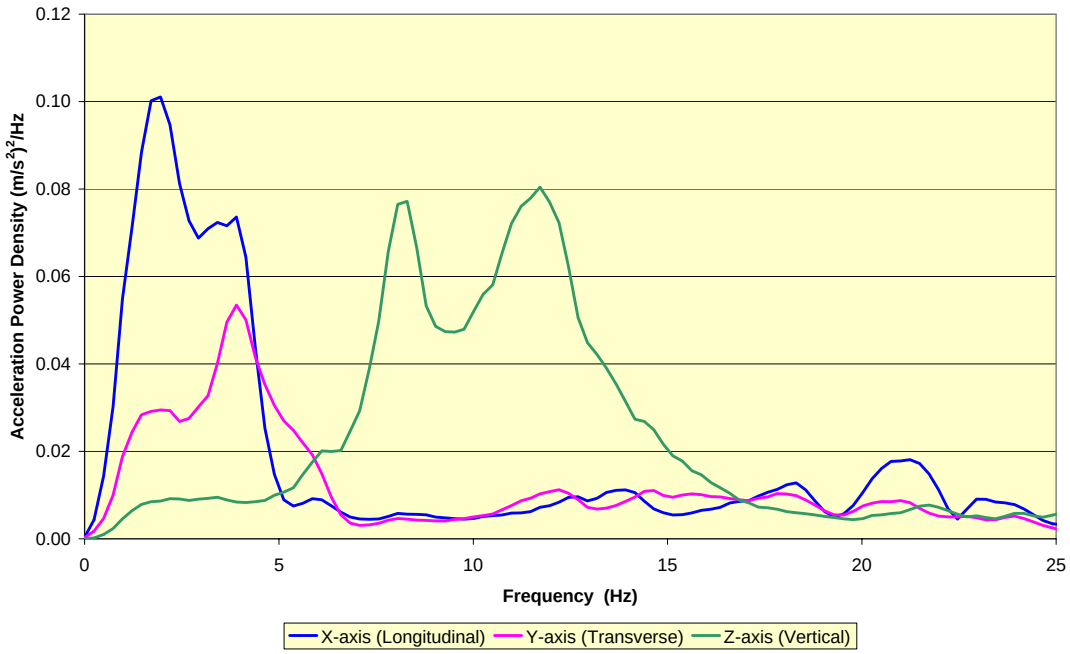

Figure A1.5.6 Liebherr Face Shovel:- acceleration power spectral density (floor) – whilst loading dump trucks

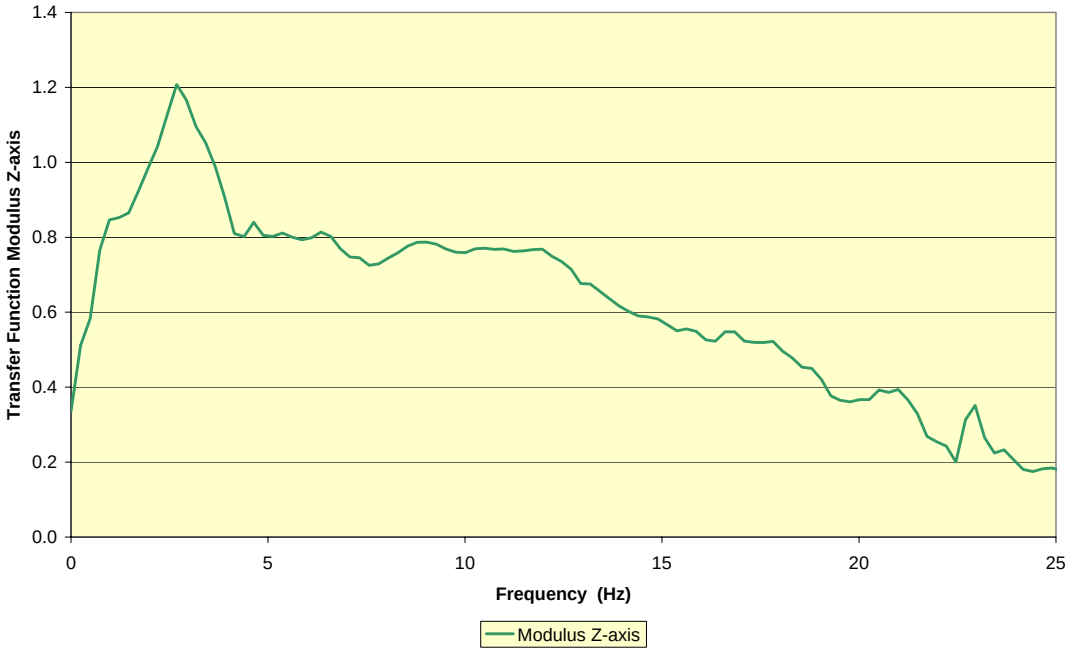

Figure A1.5.7 Liebherr Face Shovel:- seat transfer function – Magnitude –whilst loading dump trucks

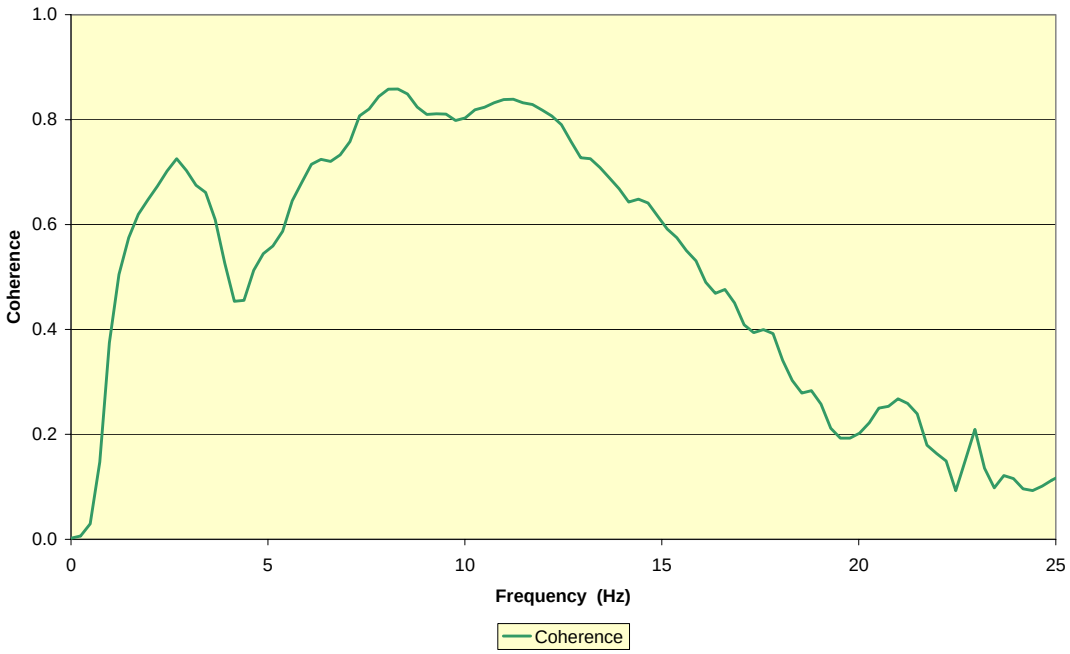

Figure A1.5.8 Liebherr Face Shovel:- seat transfer function – Coherence – whilst loading dump trucks

A1.5.3 Liebherr Face Shovel WBV Data:- Travelling On-Site

Larson Davis HVM100	SN:00215	Day	Month	Year
Location:	***Floor***	***22***	***9***	***4***
Machine:	Liebherr Tracked Face Shovel			
Model No:	R994 Litronic		Start time:	11:59
Task:	Travelling on-site			
Place:	Mountsorrel Quarry, Leics			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
00:08	**3.5**	**3.8**	**7.8**	**9.4**
8-hr est tot	*9.8*	*10.5*	*21.7*	*26.0*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.49	***0.57***	***1.12***	***1.34***

Estimated values	**VDV**	**rms/A(8)**
Time to EAV (hr):	0.2	1.6
Time to ELV (hr):	7.0	8.4

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
3.71	3.39	11.60	11.60

Larson Davis HVM100	SN:00272	Day	Month	Year
Location:	***Seat***	***22***	***9***	***4***
Machine:	Liebherr Tracked Face Shovel			
Model No:	R994 Litronic		Start time:	11:59
Task:	Travelling on-site			
Place:	Mountsorrel Quarry, Leics			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
00:08	**4.5**	**4.6**	**6.3**	**9.0**
8-hr est tot	*12.5*	*12.7*	*17.4*	*24.9*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.64	***0.70***	***1.04***	***1.40***

Estimated values	**VDV**	**rms/A(8)**
Time to EAV (hr):	0.6	1.9
Time to ELV (hr):	17.0	9.9

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
4.94	4.12	20.30	20.30

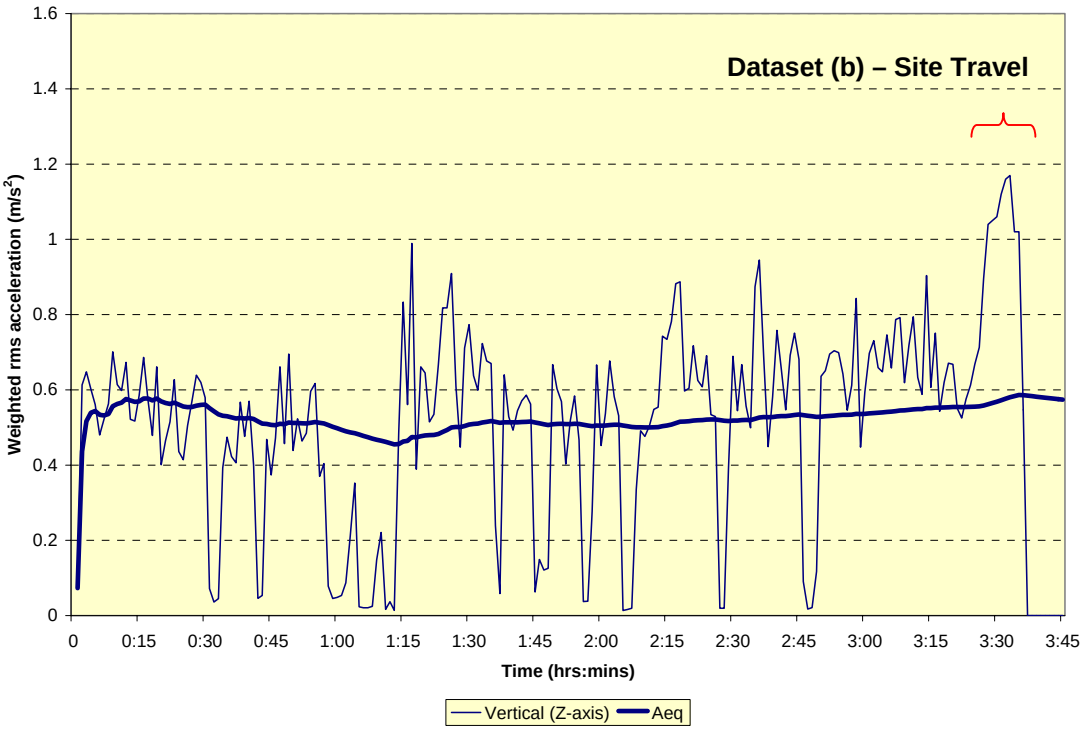

Figure A1.5.9 Liebherr Face Shovel:- time history of weighted 1-minute rms seat accelerations (Z-axis) and equivalent continuous rms acceleration (Aeq):- entire recording period

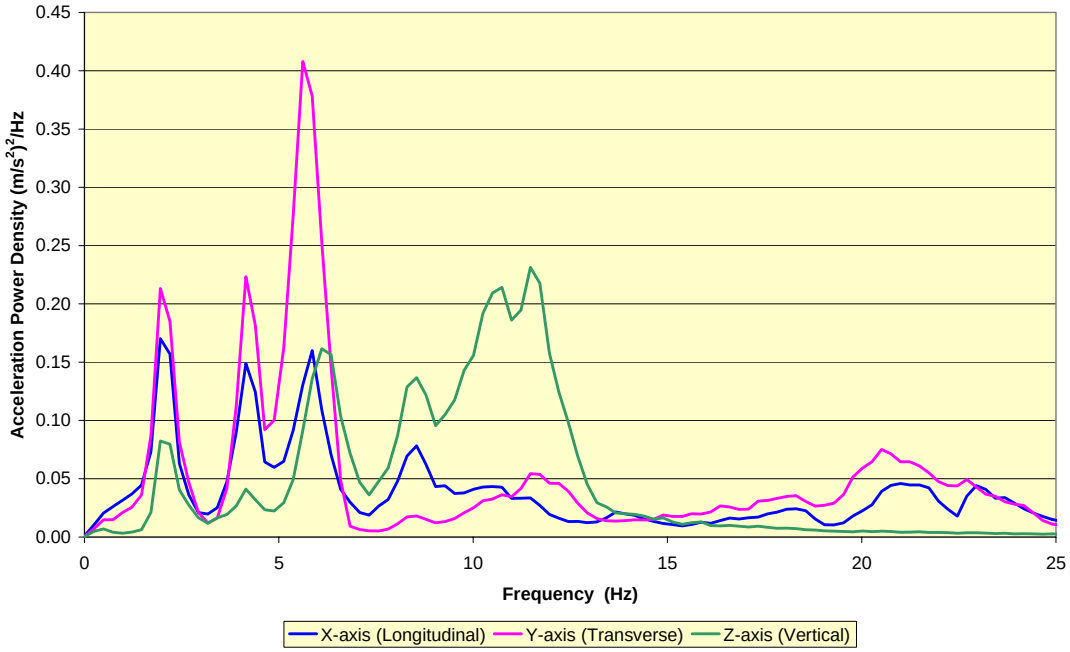

Figure A1.5.10 Liebherr Face Shovel:- acceleration power spectral density (seat) – whilst travelling on-site

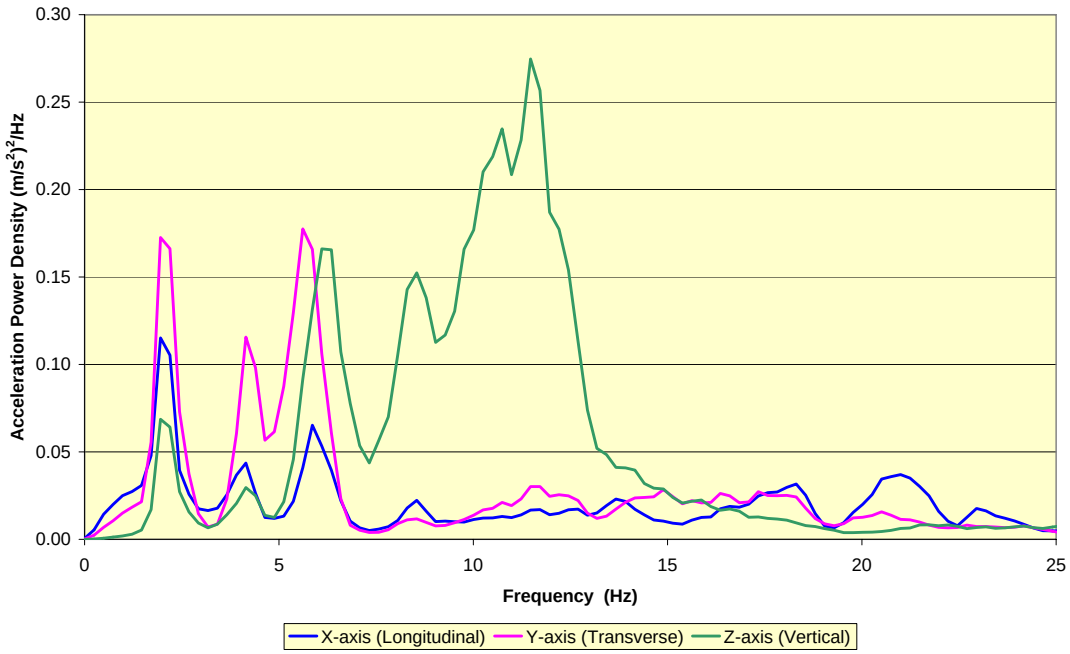

Figure A1.5.11 Liebherr Face Shovel:- acceleration power spectral density (floor) – whilst travelling on-site

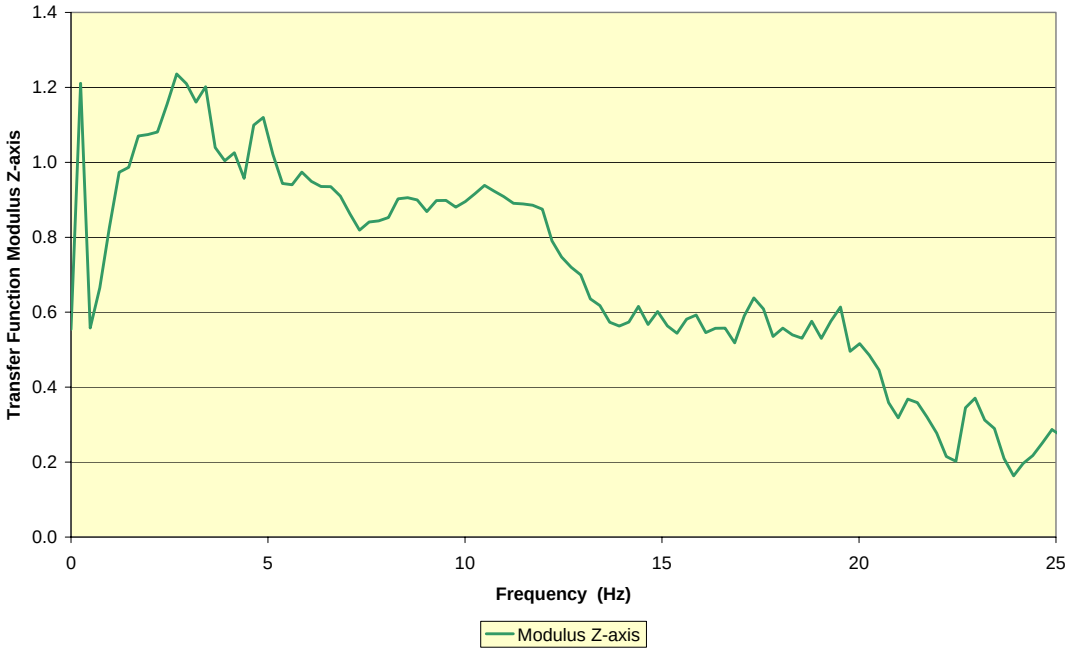

Figure A1.5.12 Liebherr Face Shovel:- seat transfer function – Magnitude –whilst travelling on-site

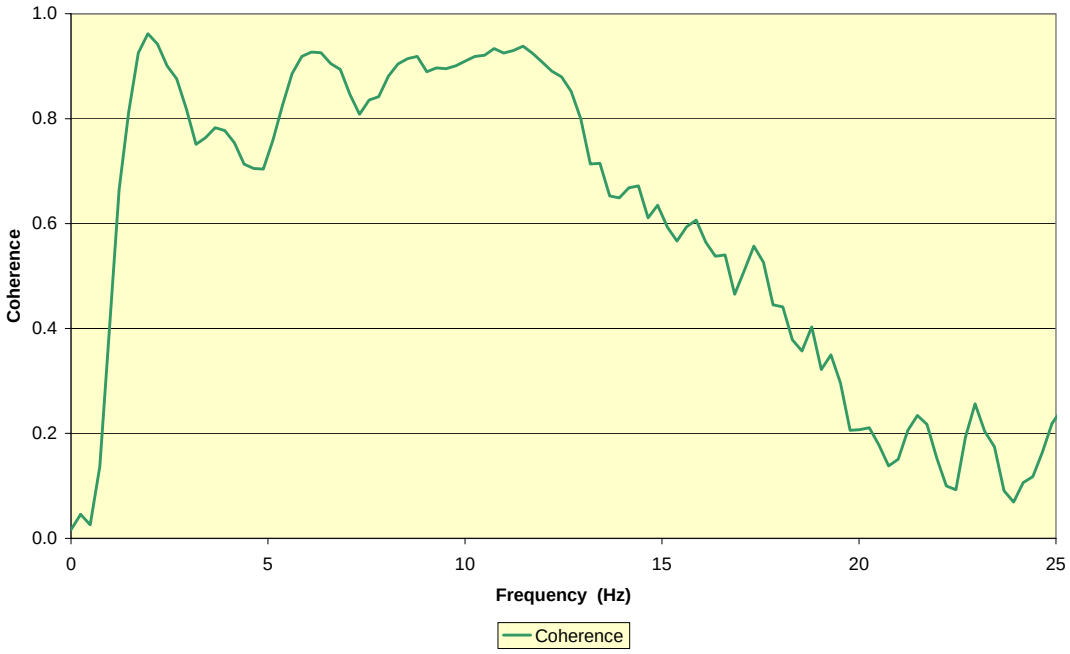

Figure A1.5.13 Liebherr Face Shovel:- seat transfer function – Coherence –whilst travelling on-site

Appendix 1.6: Machine No.6 – Bomag BW161 AD2 Twin-Drum Vibrating Roller

A1.6.1 Operational Details

Date: Thursday 14th October 2004

Location: M25 widening section, Junction 12-13
Tarmac (Southern) tarmac laying team
operating as sub-contractors on Balfour Beatty Site.
- AJS accompanied by Ken Bradley, Safety Officer, Tarmac Southern

Machine : Bomag BW161 AD2 twin-drum, articulated vibrating roller

Max. mass:	10973 kg
Operating mass:	9734 kg
Built:	2003
Engine power:	70 kW

Operator's name: Bobby:- experienced, conscientious
Weight: 105 kg
Working for: Tarmac (Southern) Ltd

Tyre pressure: N/A

Vehicle Suspension: No suspension but full width iso-mounted cab. Separate steering wheels/dual-controls mounted on each side of cab.

Seat Suspension: Grammer DS85/H/90
Mechanical, scissor type, spring and damper Z-axis suspension. In good condition. Operator's seat can be slid (on lateral rail) to either side of cab, or sited centrally. Seat remained on extreme RHS throughout duration of test.
Seat suspension initially set far too firmly for driver's weight. (apparently to raise seating position/provide better view.) Seat re-adjusted to correct weight setting before testing - driver subsequently commented on improved ride quality.

WBV Instrumentation:

Seat:- SRI ICP-type PCB 356B40 in seat pad plus operator seat presence switch
Floor:- SRI Floor Box No.3 attached to seat mounting
Both pieces of instrumentation feeding through Larson Davis Human Vibration Meters (LD 215 – Floor) & (LD 272 – Seat) and recording directly to Teac DR-C2 PC-card recorder

Site Operation:- Compacting, freshly laid (hot-rolled) asphalt immediately behind paving machine. Working at a slight angle across carriageway, travelling to and fro. Water sprayed onto roller drums to prevent material sticking. Eccentric, power-driven units in each drum create high-frequency vibrations, increasing compacting effect of machine. Prior to each change in direction, m/c vibration units are turned off. Otherwise furrowing of (relatively soft) surface would result due to vibration operating whilst m/c is momentarily stationary. During deceleration of vibration units, lower frequency spectra are generated, potentially passing (briefly) through sectors of interest to WBV. Whilst a momentary, transitory effect, this does occur a no. of times every minute.

Operational Comments:-

- Vibration levels appeared to be relatively low, but increased significantly when m/c momentarily runs partly onto previously-laid (adjacent) tarmac strip which is compacted and has solidified and therefore transmits vibration much more. Much less vibration evident when running on newly laid tarmac compacting it for the first or the second time while still hot.
- Each time the roller approaches a change in direction, the roller's internal vibration system is turned off, resulting in a reduction in vibration frequency down to zero. Upon having changed direction of travel, the vibration system is turned on once more and has to accelerate back up to operating frequency from zero. This causes a significant change in vibration frequency through the chassis of the roller, which can be felt through the feet of bystanders, particularly strong at approximately half way through acceleration to normal operating frequency.
- Driver complained of HAV through steering wheel during m/c operation (likely to be high frequency due to roller vibration system. 'Orbitrol' hydrostatic steering unit appeared to be mounted directly to cab structure, not via any anti vibration mountings.

Operational Record:-

Recording started: **12:29 hrs** **Duration:-1:34 hrs:mins**
Recording stopped: **14:02 hrs**
Analysis Period: **0:01 – 1:34 hrs**

Time (hrs:mins)	Duration (hrs:mins)	Activity : Comments
12.29	**0:01**	Recording system started
12.30	**0:02**	Operator starts work on machine
12.34	**0:06**	Compacting base asphalt surface being laid on road: repeatedly driving backwards and forwards, engaging vibration system of roller intermittently when not changing direction.
12.40	**0:12**	Momentary pause whilst checking operation of equipment: Larson Davis meters and Teac recorder both operating correctly.
12.43	**0:15**	Operation momentarily stopped due to no further progress with tarmac laying machine
12.47	**0:19**	Operation recommenced
13.30	**1:02**	Operation stopped, may have been stopped for some while
13.32	**1:04**	Operation restarted
13.40	**1:12**	Operation momentarily stopped
13.45	**1:17**	Driver leaves seat
13.47	**1:19**	Operator re-enters cab, operation recommences
14.02	**1:34**	Operation stopped

Data Analysis Comments:-

- Periods of machine idleness (at engine tickover) and/or operator absence from the driver's seat appear to cause higher Z-axis WBV values;
- Datasets derived from periods when the driver is "on-seat" generate significantly lower Z-axis WBV levels than those relating to the entire measurement period (particularly for "seat" WBV values;
- High Z-axis rms seat acceleration values (see Figure A1.6.3) appear to coincide with the periods when the driver is "off-seat" (see Figure A1.6.4).

Figure A1.6.1 Bomag BW161 AD2 10-tonne articulated twin-drum vibrating roller compacting freshly-laid hot asphalt on M25

A1.6.2 Bomag BW161 Twin-Drum Vibrating Roller Whole-Body Vibration Data

Larson Davis HVM100	SN:00215	Day	Month	Year
Location:	***Floor***	***14***	***10***	***4***
Machine:	Bomag 10 tonne Artic Twin Drum Vibrating Roller			
Model No:	BW 161 AD2		Start time:	12:28
Task:	Compacting Tarmac			
Place:	M25, junc 12 - 13			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
01:45	**3.0**	**4.6**	**6.9**	**8.7**
8-hr est tot	*4.4*	*6.7*	*10.0*	*12.7*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.21	***0.26***	***0.56***	***0.65***

Estimated values	**VDV**	**rms/A8**
Time to EAV (hr):	5.4	6.4
Time to ELV (hr):	154.0	33.7

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
2.37	4.86	3.87	5.04

Larson Davis HVM100	SN:00272	Day	Month	Year
Location:	***Seat***	***14***	***10***	***4***
Machine:	Bomag 10 tonne Artic Twin Drum Vibrating Roller			
Model No:	BW 161 AD2		Start time:	12:28
Task:	Compacting Tarmac			
Place:	M25, junc 12 - 13			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
01:45	**4.2**	**6.1**	**9.6**	**11.9**
8-hr est tot	*6.1*	*8.9*	*14.0*	*17.4*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.29	***0.38***	***0.54***	***0.72***

Estimated values	**VDV**	**rms/A8**
Time to EAV (hr):	1.4	6.9
Time to ELV (hr):	40.6	36.5

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
3.30	5.39	14.00	14.40

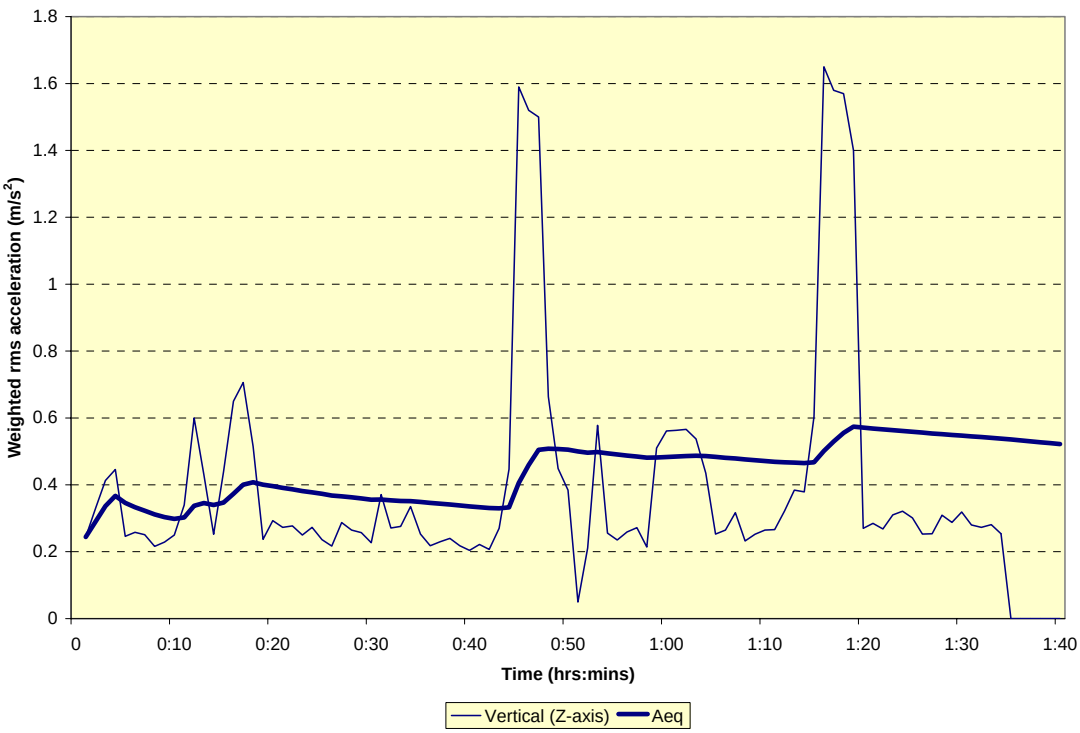

Figure A1.6.2 Bomag BW161 10-tonne twin drum vibrating roller:- time history of weighted 1-minute rms seat accelerations (Z-axis) and equivalent continuous rms acceleration (Aeq) – entire recording period

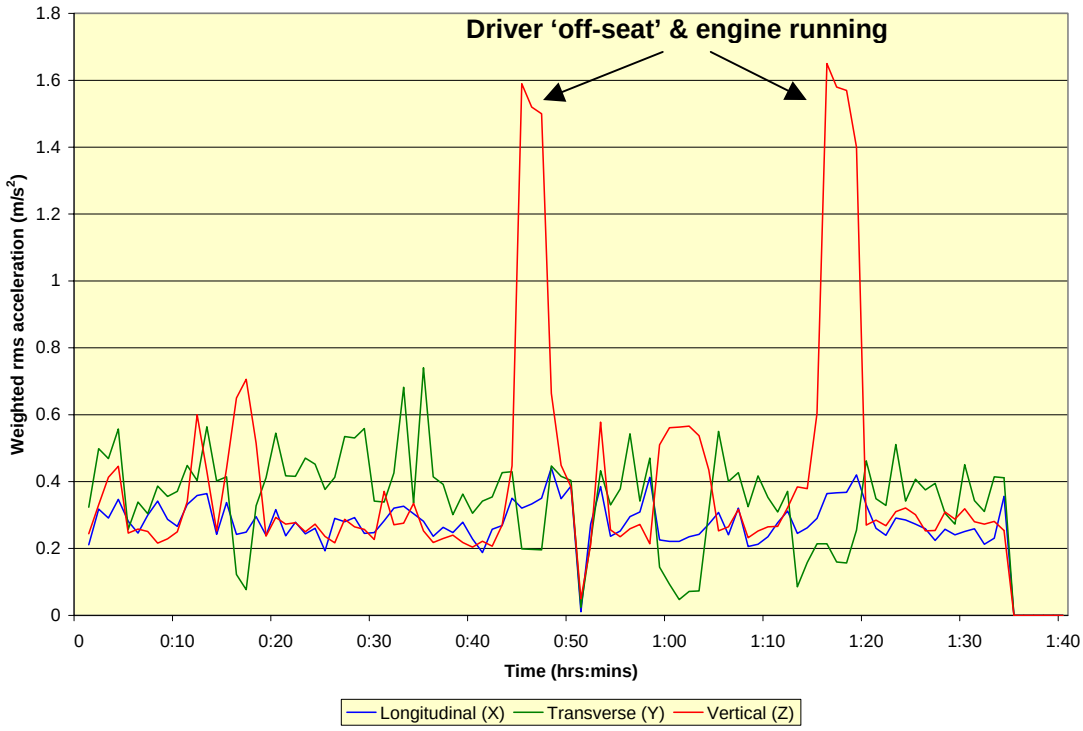

Figure A1.6.3 Bomag BW161 10-tonne twin drum vibrating roller:- time histories of weighted 1-minute rms seat accelerations (X, Y and Z-axes)

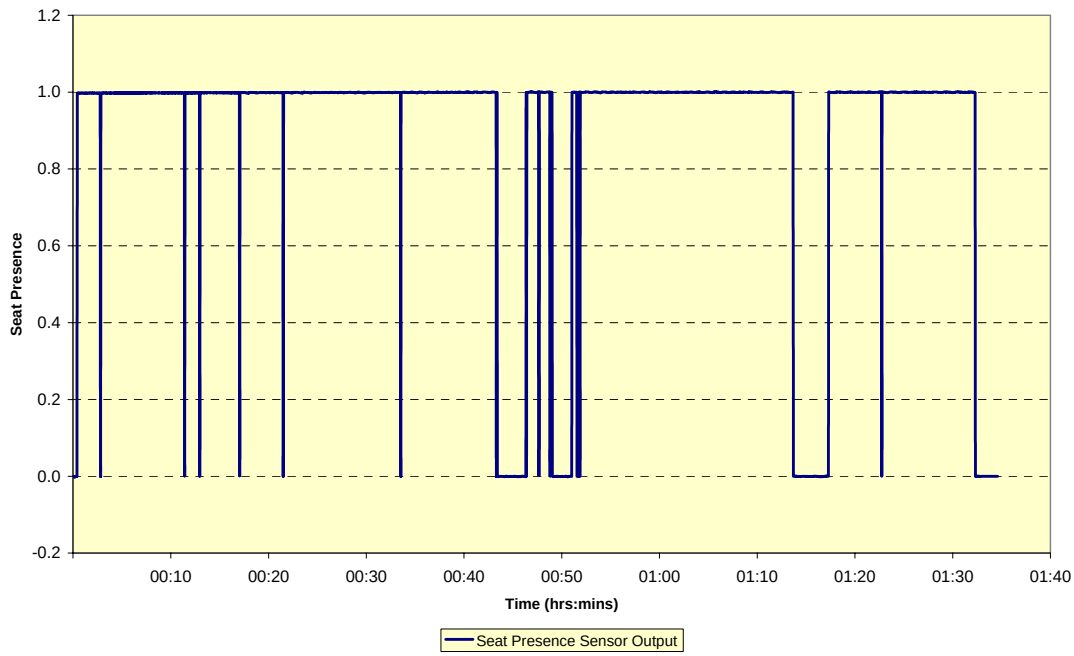

Figure A1.6.4 Bomag BW161 10-tonne twin drum vibrating roller:- driver seat presence sensor output

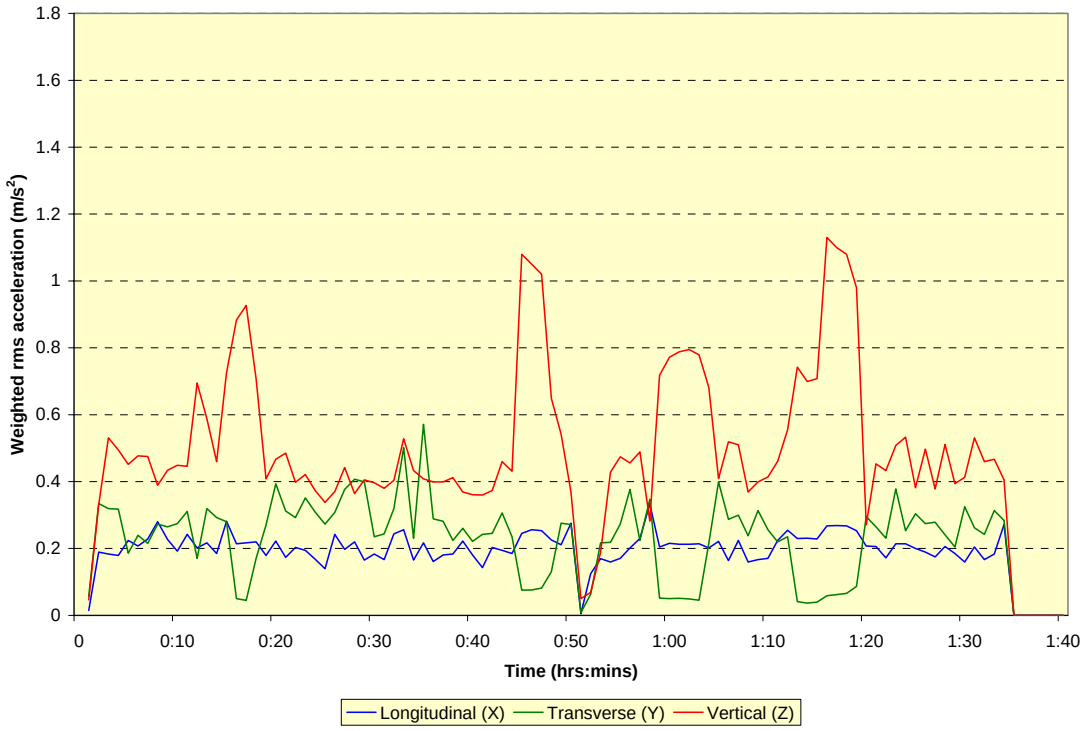

Figure A1.6.5 Bomag BW161 10-tonne twin drum vibrating roller:- time histories of weighted 1-minute rms floor accelerations (X, Y and Z-axes)

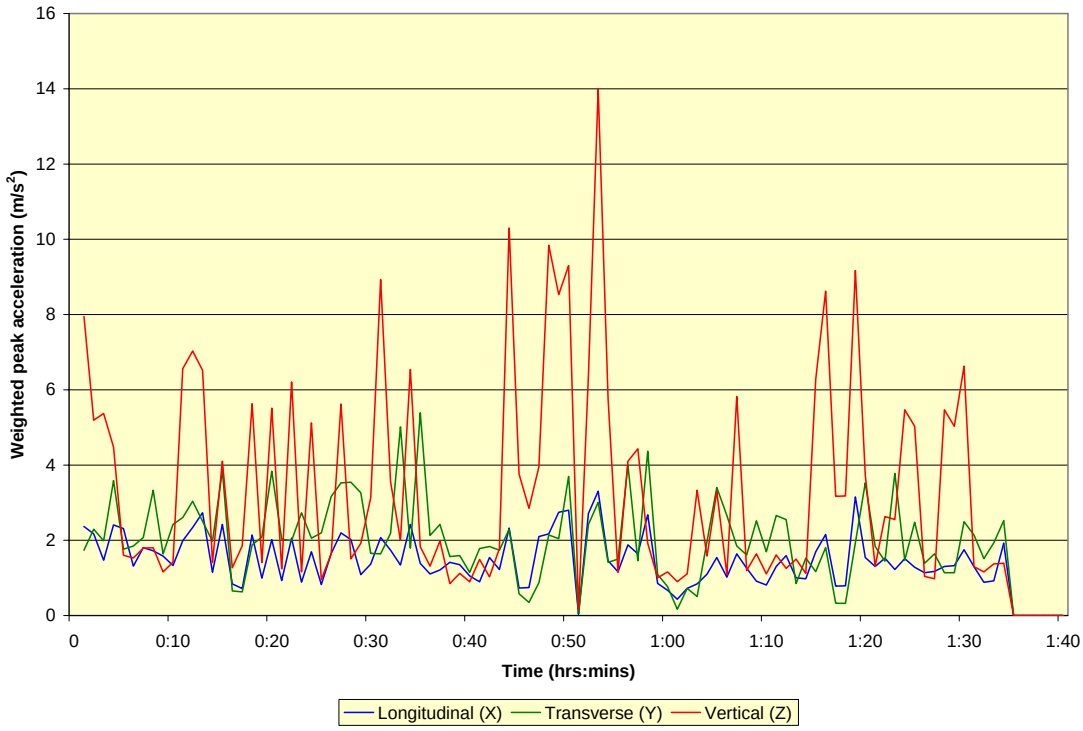

Figure A1.6.6 Bomag BW161 10-tonne twin drum vibrating roller:- time histories of weighted 1-minute peak seat accelerations (X, Y and Z-axes)

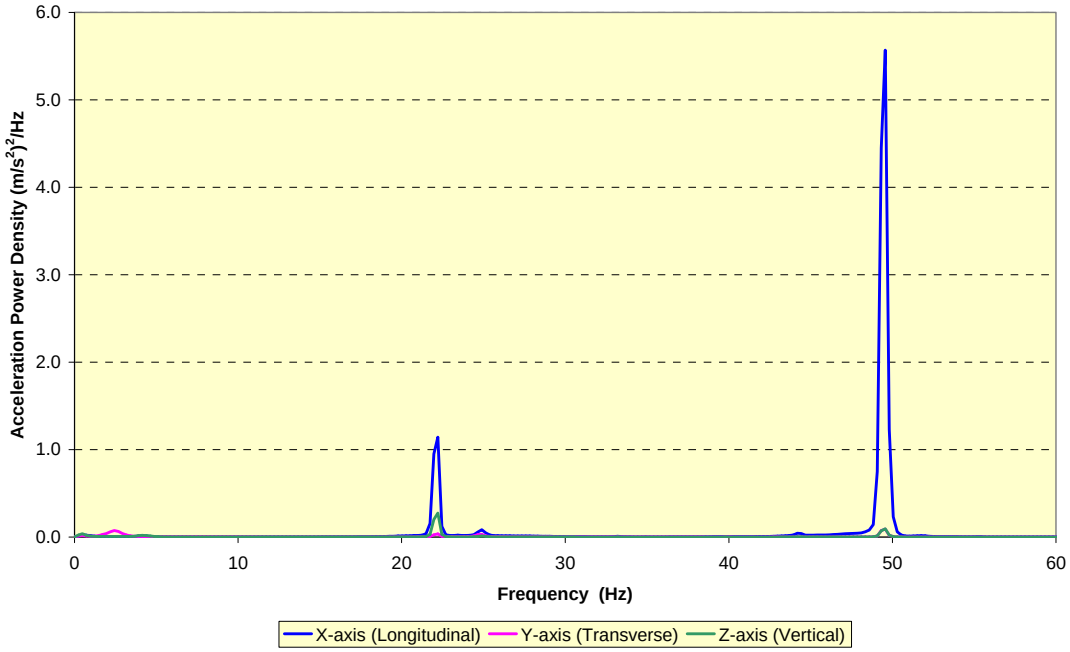

Figure A1.6.7 Bomag BW161 10-tonne twin drum vibrating roller:- acceleration power spectral density (seat) – for sections of recording period when driver is "on-seat"

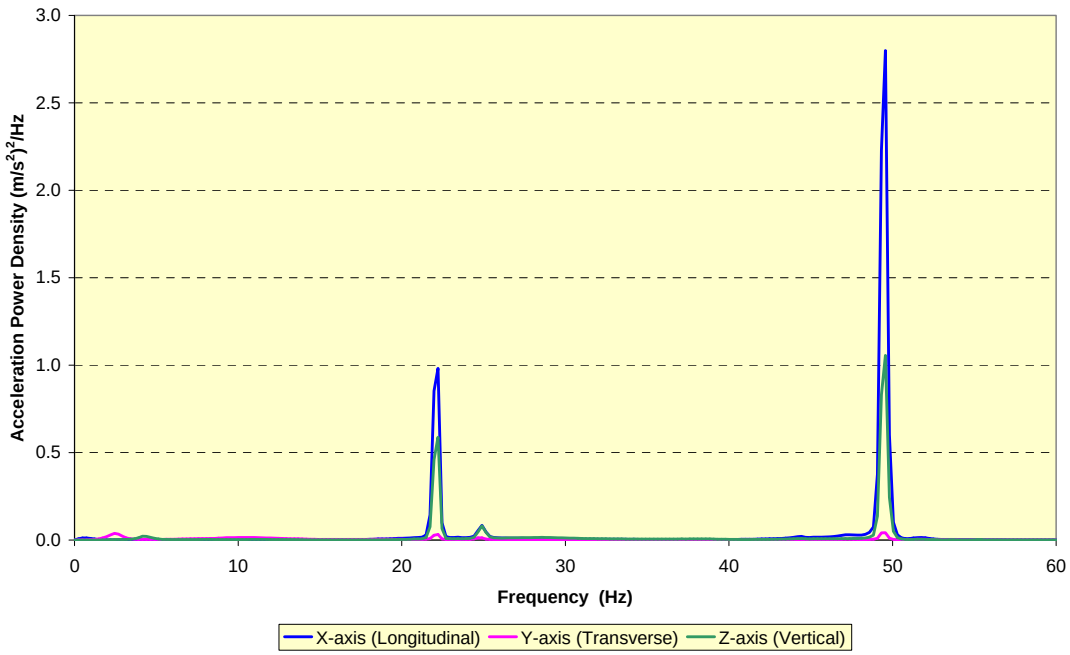

Figure A1.6.8 Bomag BW161 10-tonne twin drum vibrating roller:- acceleration power spectral density (floor) – for sections of recording period when driver is "on-seat"

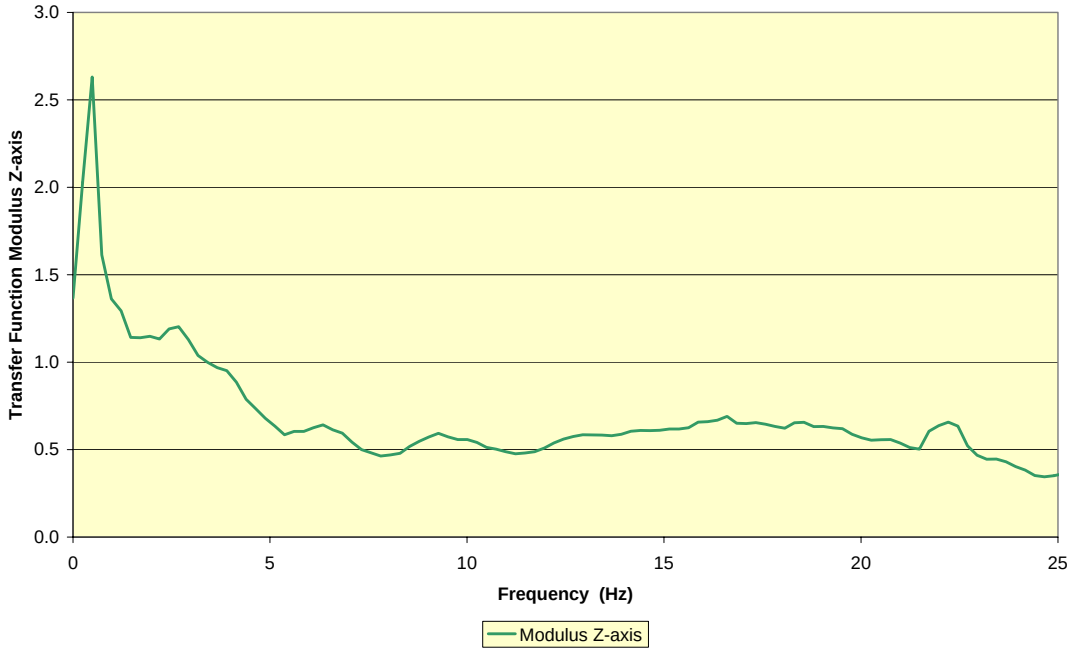

Figure A1.6.9 Bomag BW161 10-tonne twin drum vibrating roller:- seat transfer function – Magnitude – driver "on-seat"

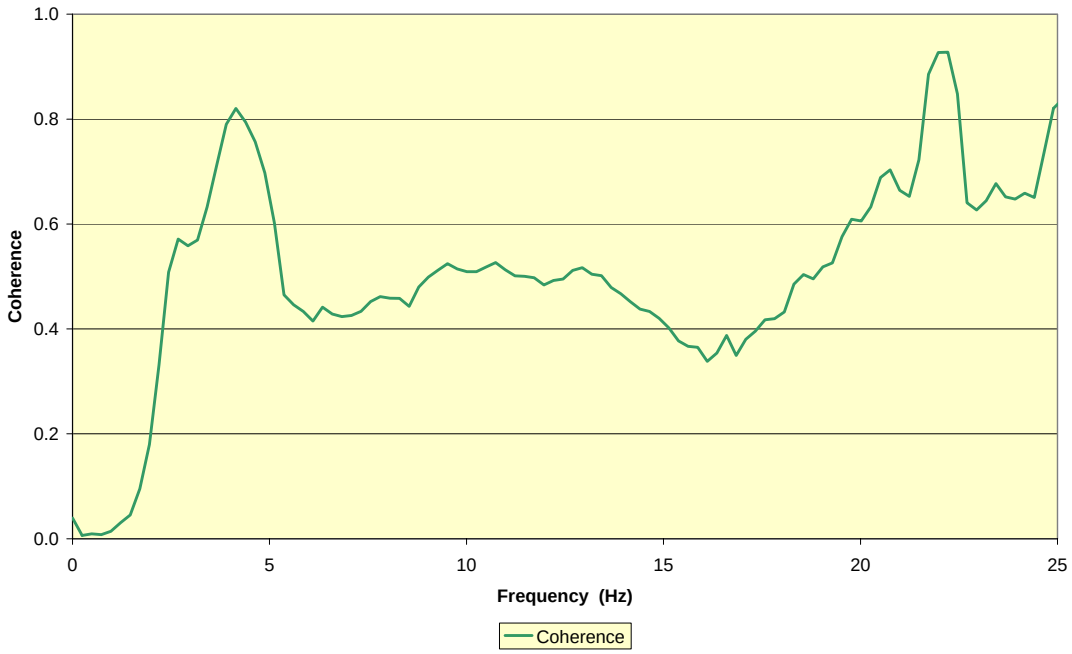

Figure A1.6.10 Bomag BW161 10-tonne twin drum vibrating roller:- seat transfer function – Coherence - driver "on-seat"

Appendix 1.7: Machine No.7 – Bomag BW138 AD Twin-Drum Vibrating Roller

A1.7.1 Operational Details

Date: Thursday 14th October 2004

Location: M25 widening section, Junction 12-13
Tarmac (Southern) tarmac laying team operating
as sub-contractors on Balfour Beatty Site.
- AJS accompanied by Ken Bradley, Safety Officer, Tarmac Southern

Machine Make: Bomag BW138AD small, twin-drum, articulated vibrating roller

Max. mass:	?kg
Operating mass:	4189 kg
Built:	2002
Engine power:	29.0 kW

Operator's name: ??? experienced, conscientious
Weight: 89 kg
Working for: Tarmac (Southern) Ltd

Tyre pressure: N/A

Vehicle Suspension: Operators platform iso-mounted. No cab, but roll-bar fitted.

Seat Suspension: Grammer MSG12 low-height (rear suspension, front squab pivot) suspension seat fitted centrally on operator's platform. However, seat suspension mechanism not functioning correctly - some suspension present but not possible to adjust for operator's mass. Lap-type seatbelt worn by operator.

WBV Instrumentation:
Seat:- - B&K Piezoelectric seat pad
- No seat switch installed (operator present throughout measurement period)
Floor:- - ICP-type PCB 356B40 3-axis accelerometer (from SRI PCB seat pad) attached via magnetic mounting
Both pieces of instrumentation feeding through Larson Davis Human Vibration Meters (LD 215 – Floor) & (LD 272 – Seat) and recording directly to Teac DR-C2 PC-card recorder

Site Operation:- Machine being used for finishing / compacting edges of newly-laid tarmac and removing small blemishes (joins) left by larger (10 tonne) roller preceding it. Normally used (in this application) without vibration system operating. During test period (after 50 mins) roller vibration system engaged only for short period.

Operational Record:-

Recording started: **15:12 hrs** **Duration:-** **1:00 hrs**
Recording stopped: **16:11 hrs**

Data Analysis Period: **0:01 – 0:55 hrs** **Analysis Duration:-** **55 mins**

Time (hrs:mins)	Duration (hrs:mins)	Activity : Comments
15.12	**0:01**	Instrumentation placed on smaller Bomag articulated vibrating roller.
15.22	**0:11**	Instrumentation on roller checked, all working OK. Values on Larson Davies meters appear to be changing
15.38	**0:27**	Roller stops working waiting for further surface to be laid,
13.44	**0:33**	Recommenced rolling
16.01	**0:50**	Roller vibration system turned on, not having been used up until now. Now actually operating
16.02	**0:51**	Vibration system turned off.
16.06	**0:55**	Operation stopped momentarily
16.08	**0:57**	Travelling back up to car, recorder still operating
16.11	**1:00**	Machine stationary awaiting removal of instrumentation.

Figure A1.7.1 Bomag BW138 AD 4-tonne articulated twin-drum vibrating roller finishing partially-compacted hot asphalt on M25

A1.7.2 Bomag BW138 Twin-Drum Vibrating Roller Whole-Body Vibration Data

Larson Davis HVM100	SN:00215	Day	Month	Year
Location:	***Floor***	***14***	***10***	***4***
Machine:	Bomag 4 tonne Artic Twin Drum Vibrating Roller			
Model No:	BW 138 AD		Start time:	15:12
Task:	Compacting Tarmac			
Place:	M25, junc 12 - 13			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
00:55	**3.9**	**5.0**	**7.0**	**9.4**
8-hr est tot	*6.7*	*8.6*	*12.0*	*16.2*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.26	***0.35***	***0.56***	***0.71***

Estimated values	**VDV**	**rms/A(8)**
Time to EAV (hr):	2.6	6.4
Time to ELV (hr):	75.1	33.8

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
5.74	9.56	16.80	19.20

Larson Davis HVM100	SN:00272	Day	Month	Year
Location:	***Seat***	***14***	***10***	***4***
Machine:	Bomag 4 tonne Artic Twin Drum Vibrating Roller			
Model No:	BW 138 AD		Start time:	15:11
Task:	Compacting Tarmac			
Place:	M25, junc 12 - 13			

Total VDV

Time	X	Y	Z	Sum
00:55	**4.3**	**5.4**	**7.4**	**10.1**
8-hr est tot	*7.4*	*9.3*	*12.7*	*17.4*

Average rms (Leq)

X	Y	Z	Sum
0.28	***0.38***	***0.48***	***0.71***

	VDV	**rms/A8**
Time to EAV (hr):	2.1	8.8
Time to ELV (hr):	59.8	46.8

Maximum peak value

X	Y	Z	Sum
6.54	11.55	12.18	14.80

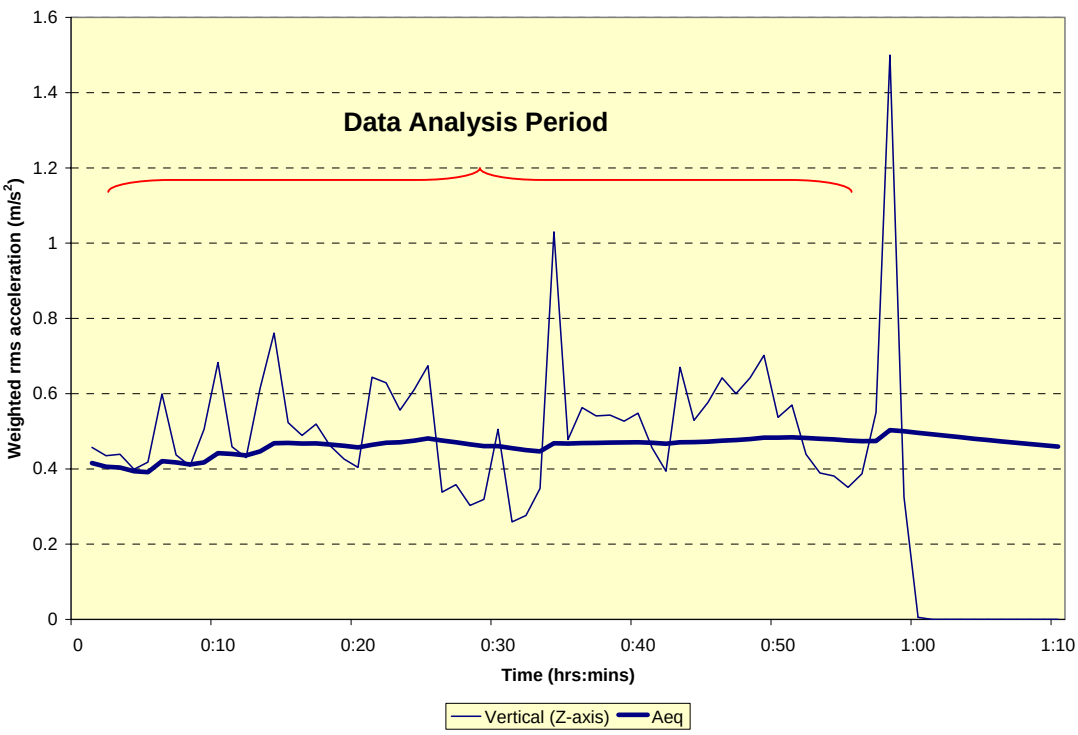

Figure A1.7.2 Bomag BW138 4-tonne twin drum vibrating roller:- time history of weighted 1-minute rms seat accelerations (Z-axis) and equivalent continuous rms acceleration (Aeq)

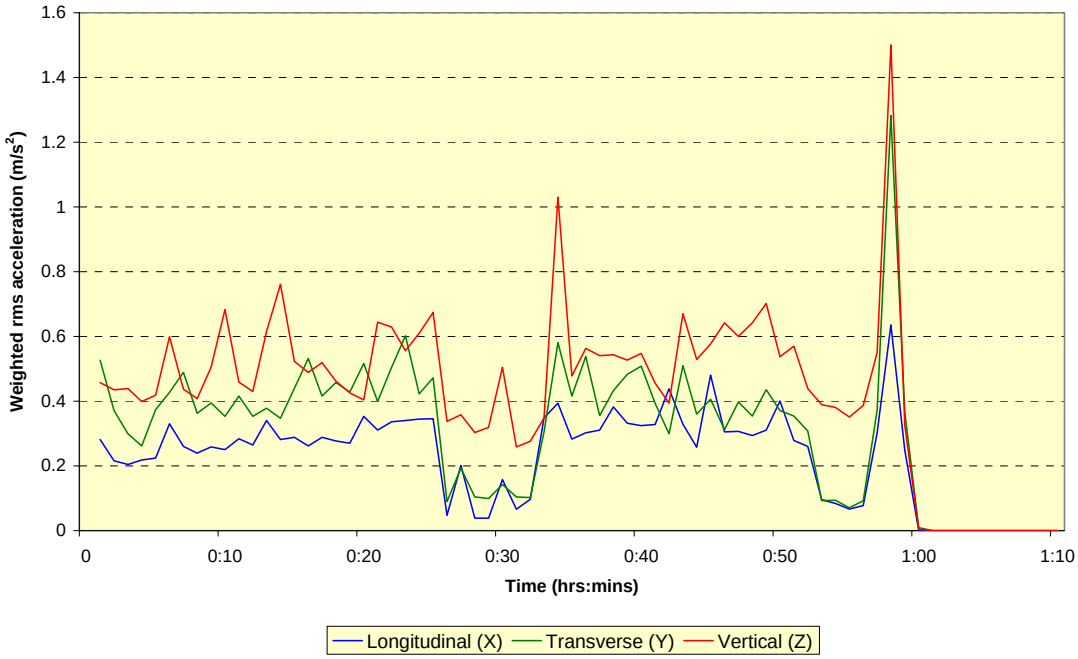

Figure A1.7.3 Bomag BW138 4-tonne twin drum vibrating roller:- time histories of weighted 1-minute rms seat accelerations (X, Y and Z-axes)

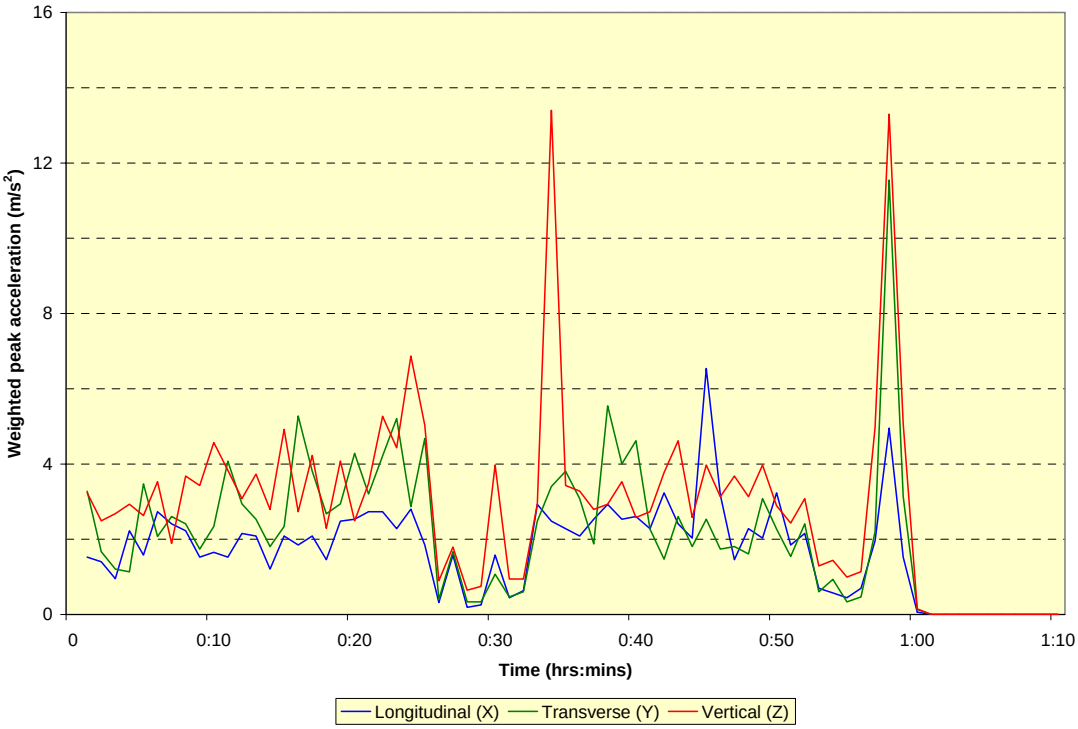

Figure A1.7.4 Bomag BW138 4-tonne twin drum vibrating roller:- time histories of weighted 1-minute peak seat accelerations (X, Y and Z-axes)

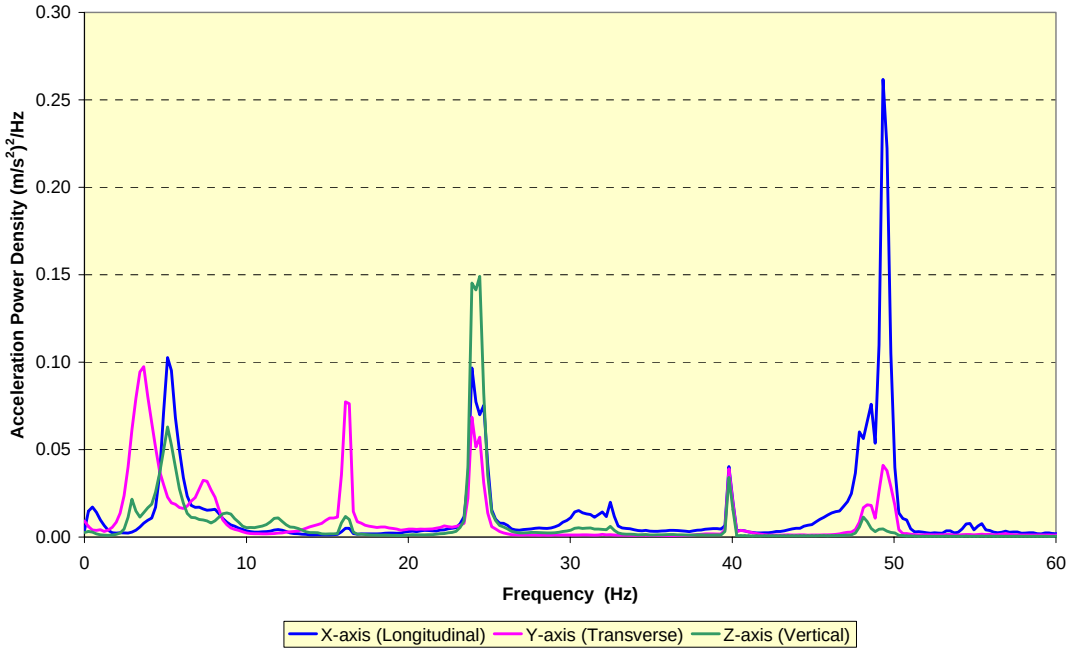

Figure A1.7.5 Bomag BW138 4-tonne articulated twin drum vibrating roller:- acceleration power spectral density (seat)

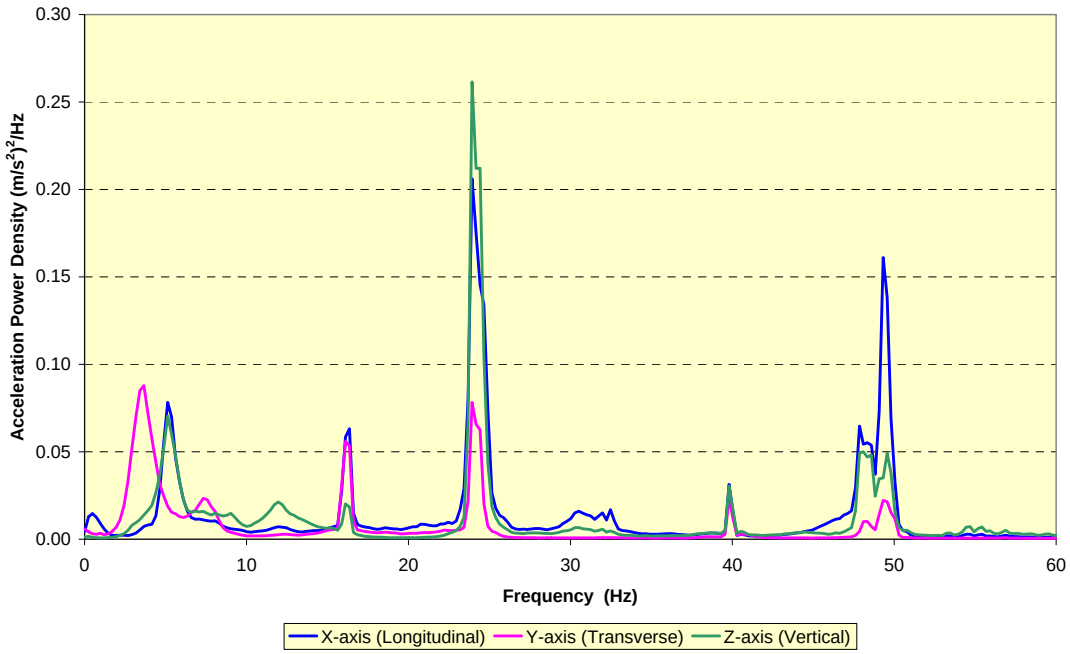

Figure A1.7.6 Bomag BW138 4-tonne articulated twin drum vibrating roller:- acceleration power spectral density (floor)

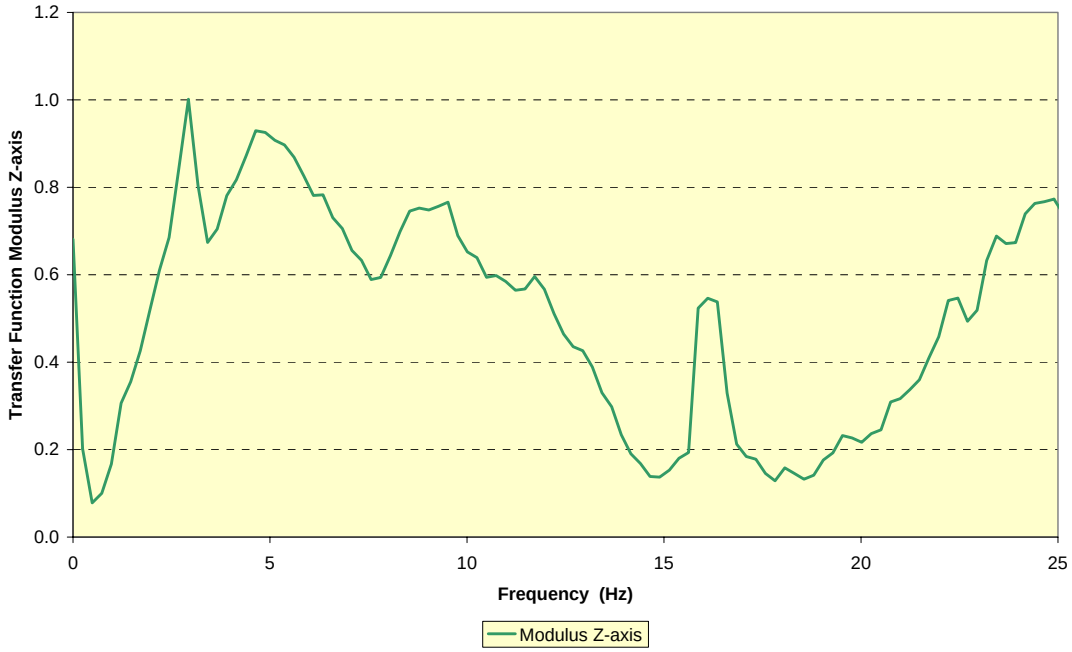

Figure A1.7.7 Bomag BW138 4-tonne articulated twin drum vibrating roller:- seat transfer function – Magnitude

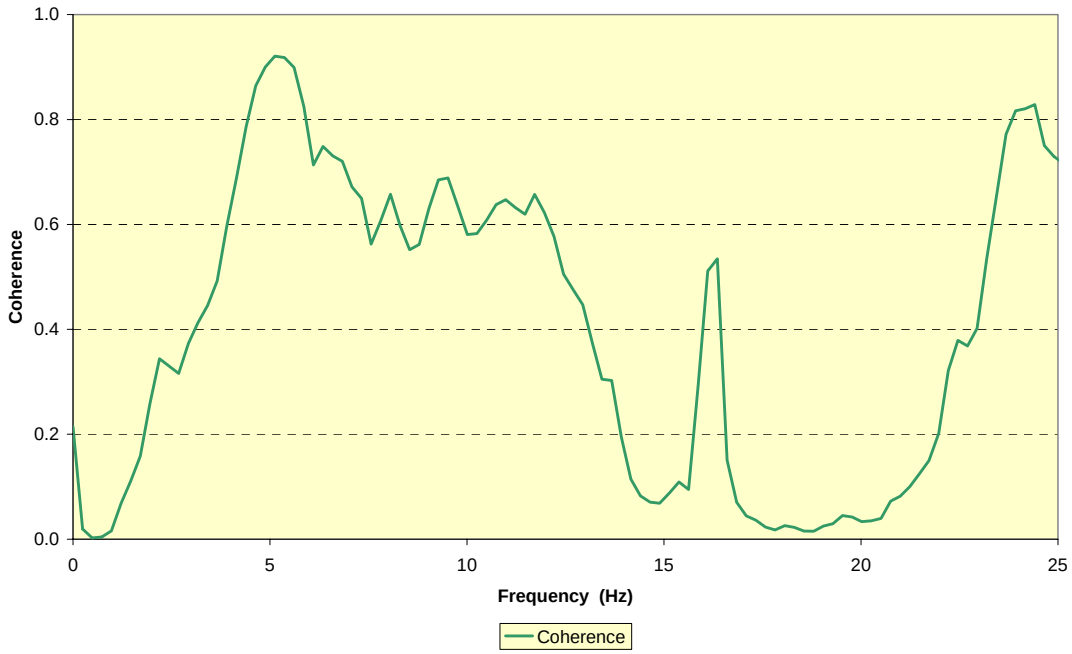

Figure A1.7.8 Bomag BW138 4-tonne articulated twin drum vibrating roller:- seat transfer function – Coherence

Appendix 1.8: Machine No.8 – Caterpillar 950F Series II Articulated Loading Shovel

A1.8.1 Operational Details

Date: Thursday 4th November 2004

Location: Hanson plc
St Ives Coating Plant
Water Meadow Lane
St Ives

Machine Make: Caterpillar 950F Series II articulated loading shovel
Model: 950F2
P.I.N.: 8TK03687

Max. mass:	kg
Operating mass:	17670 kg
Built:	1995
Engine power:	126.8 kW
Recorded engine hours:	17030 hrs
Wheelbase:	3.30 m
Wheel track:	2.20 m

Operator's name: Mick, experienced, conscientious, swift but with v.great attention to detail
Weight: 83.4 kg
Working for:

	Front	**Rear**
Tyre size(s):	23.5 R25 tubeless radial Construction bar tread	23 R25 radial - slick
Tyre pressure:	42/42 psi (L/R)	37/34 psi (L/R)

Machine chassis: Vertically - rigid articulation joint
- Rigidly mounted front axle
- Centrally - pivoting rear axle

Vehicle Suspension: None

Operator's Seat: Sears Ser. No. 144944
Scissor-type Z-axis mechanical spring & hydraulic damper suspension seat (high back, armrests, lap belt (not worn))
- Well-adjusted to operator's mass and in good condition despite machine age (replaced during m/c lifetime?) Apparently not!

WBV Instrumentation:

Seat:- SRI ICP-type PCB 356B40 in seat pad plus operator seat presence switch
Floor:- SRI Floor Box No.3 attached to seat mounting
Both pieces of instrumentation feeding through Larson Davis Human Vibration Meters (LD 215 – Floor) & (LD 272 – Seat) and recording directly to Teac DR-C2 PC-card recorder

Site Operation:- General bulk materials handling duties in asphalt plant. Responsible for loading all plant feed hoppers with wide range of sands and aggregates from adjacent stockpiles. Also undertakes heaping-up stockpiles, following deliveries of new materials by lorry. Entire aggregate input to plant is handled by this single machine. Usual operating period is 6.30 a.m. to 2.00 pm, plus subsequent site/plant tidying. Machine is in relatively continuous operation throughout. No defined rest breaks.

Operational Comments:-

- Machine is kept in extremely good operating condition despite being 9 years old. Operator appears very experienced and extremely moderate in operation, keeping machine in extremely good condition and having an extremely efficient operating technique. This is reflected in the age and the condition of the machine;
- Loading plant feed hoppers involves repetitive travel from stockpiles - reversing and then driving 180° in the opposite direction up an approx. 15° slope and dumping in hoppers. Operating surface smooth asphalt;
- Sedate operation of machine around yard, especially with loaded bucket, is required to prevent spilling contents of bucket all over the place!
- No particular machine operation seems to generate high levels of whole body vibration, with the possible exception of slight vertical and longitudinal vibration during tipping into feed hoppers, and also longitudinal vibration whilst pushing up stockpile heaps following tipping from lorries: otherwise seems to be relatively low vibration levels during all operations;
- Majority of vibration appears to occur when emptying machine bucket and shaking material out into feed hoppers, using edge of bucket to heap material in hoppers upon discharge;

Operational Record:-

Recording started:	**08:52 hrs**	**Duration:-**	**5:54 hrs**
Recording stopped:	**14:45 hrs**		
Data Analysis Period:	**0:01 – 4:49 hrs**	**Analysis Duration:**	**4:49 hrs:mins**

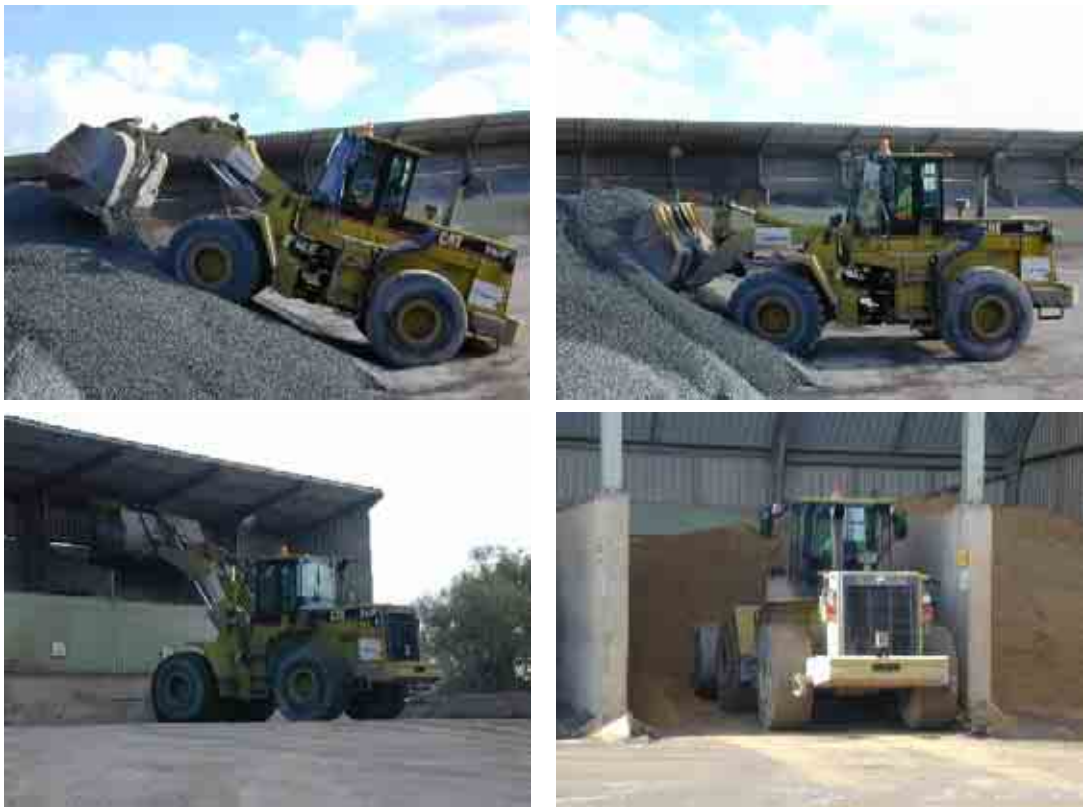

Figure A1.8.1 CAT 950F II articulated loading shovel feeding asphalt plant with aggregate

Time (hrs:mins)	Duration (hrs:mins)	Activity : Comments
08:52	**0:01**	Recording started
0852	**0:01**	Vehicle drives from weighbridge area to stockpile and begins loading plant feed hoppers. Operating surface smooth asphalt.
08.57	**0:05**	Completes loading operation for moment and scrapes area in front of feed hoppers with front edge of bucket
08.58	**0:06**	Operation complete for moment.
09.01	**0:09**	Drives round to outlet hopper and positions under outlet hopper to check whether collect material that has apparently stuck
09.00	**0:08**	Checked output of Larsen Davies meters: both seat and floor meters showing outputs
09.06	**0:14**	Returns to main yard and scrapes yard surface, cleaning up with bucket edge. Immediately after 09.06 hrs begins loading from stock pile once more and filling feed hoppers.
09.10	**0:18**	Stops loading whilst delivery of raw material arrives and is tipped
09.15	**0:23**	Delivery tipped, Mick now pushes up material on stock pile and heaps recently delivered material.
09.17	**0:25**	Finishes pushing up stock pile returns to loading feed hoppers from stockpile.
09.24	**0:32**	Carries on loading hoppers
09.26	**0:34**	Scraping yard with bucket edge
09.28	**0:36**	Returns to loading feed hoppers from stock pile
09.31	**0:39**	Leaves feeding area and positions machine under asphalt delivery chutes
09.38	**0:46**	Returns to loading in feed hoppers from stock piles
09.41	**0:49**	Driver leaves cab - cleaning windows and outside
09.45	**0:53**	Finished cleaning cab - begins work once more loading in feed hoppers from stock piles.
09.52	**1:00**	Break for cup of tea
09.55	**1:03**	Recommences loading feed hoppers from stockpiles
10.29	**1:37**	Machine brought to front of coating plant driver leaves cab
10.30	**1:38**	Driver re-enters cab
10.31	**1:39**	Driver collects overflow material from front of coating plant and returns to stockpiles
10.44	**1:52**	Driver returns to lorry loading area under outlets from batching plant and scrapes floor immediately underneath lorry loading area.
10.47	**1:55**	Operator returns to loading feed hoppers from stockpiles.
11.07	**2:15**	Returns to weighbridge area - driver leaves cab
11.10	**2:18**	Driver returns to cab - machine moves from weighbridge area. Proceeds to load feed hoppers from stockpile area.
11.57	**3:05**	Machine returns to weighbridge area, driver leaves cab
12.01	**3:09**	Driver re-enters machine which now leaves weighbridge area and returns to stockpiles and proceeds to load feed hoppers from stockpiles.
12.13	**3:21**	Operations come to an end - driver leaves cab
12.21	**3:29**	Driver re-enters cab
12.22	**3:30**	Heaps up recently delivered granite chippings
12.25	**3:33**	Returns to loading feed hoppers from stockpiles
12.29	**3:37**	Heaps up newly delivered heap of granite chippings
12.31	**3:39**	Returns and heaps up other stock pile.
12.33	**3:41**	Completes heaping - travels to asphalt discharge hoppers
12.34	**3:42**	Returns to supply feed hoppers from stockpile
12.38	**3:46**	Machine returns to weighbridge area driver leaves cab
12.41	**3:49**	Driver returns to cab machine returns to stockpile area
13.39	**4:47**	Driver returns vehicle to weighbridge area and leaves cab.
13.59	**5:07**	Operator returns to machine and returns to stockpile area to feed hoppers
14.45	**5:53**	Operator returns to weighbridge area and leaves machine
14.45	**5:53**	Recording stopped.

A1.8.2 CAT 950F II Articulated Loading Shovel Whole-Body Vibration Data

Larson Davis HVM100	SN:00215	Day	Month	Year
Location:	***Floor***	***4***	***11***	***2004***
Machine:	Caterpillar Artic. Loading Shovel			
Model No:	950F II		Start time:	09:52
Task:	Feeding tarmac plant			
Place:	St.Ives, Cambs			

Total VDV ($m/s^{1.75}$)

Time	X	Y	Z	Sum
04:49	**10.2**	**8.7**	**7.2**	**15.2**
8-hr est tot	*11.6*	*9.9*	*8.2*	*17.3*

Average r.m.s. (Aeq) (m/s^2)

X	Y	Z	Sum
0.45	***0.41***	***0.32***	***0.68***

Estimated values	**VDV**	**rms/A(8)**
Time to EAV (hr):	3.0	9.9
Time to ELV (hr):	86.2	52.3

Maximum peak value (m/s^2)

X	Y	Z	Sum
8.79	5.12	7.67	9.60

Larson Davis HVM100	SN:00272	Day	Month	Year
Location:	***Seat***	***4***	***11***	***2004***
Machine:	Caterpillar Artic. Loading Shovel			
Model No:	950F II		Start time:	09:51
Task:	Feeding tarmac plant			
Place:	St.Ives, Cambs			

Total VDV ($m/s^{1.75}$)

Time	X	Y	Z	Sum
04:49	**12.6**	**11.0**	**16.5**	**23.4**
8-hr est tot	*14.3*	*12.5*	*18.7*	*26.6*

Average r.m.s. (Aeq) (m/s^2)

X	Y	Z	Sum
0.59	***0.53***	***0.38***	***0.88***

Estimated values	**VDV**	**rms/A(8)**
Time to EAV (hr):	0.5	5.7
Time to ELV (hr):	12.8	30.1

Maximum peak value (m/s^2)

X	Y	Z	Sum
9.31	6.64	23.60	23.70

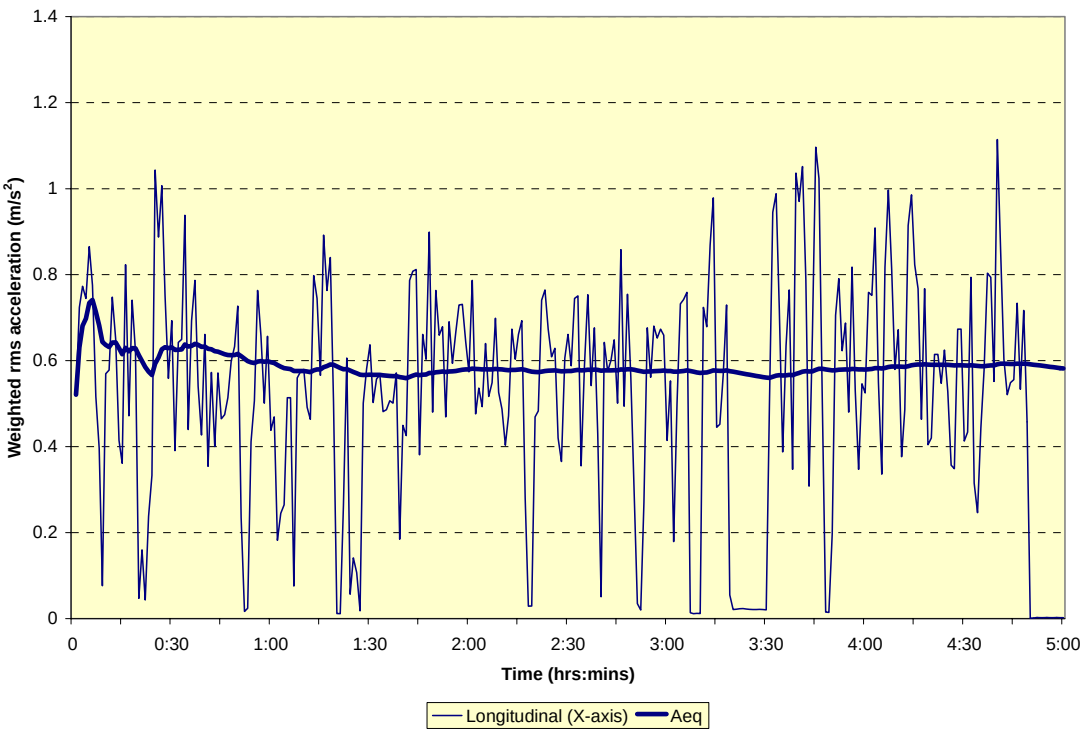

Figure A1.8.2 CAT 950F II articulated loading shovel:- time history of weighted 1-minute rms seat accelerations (X-axis) and equivalent continuous rms acceleration (Aeq)

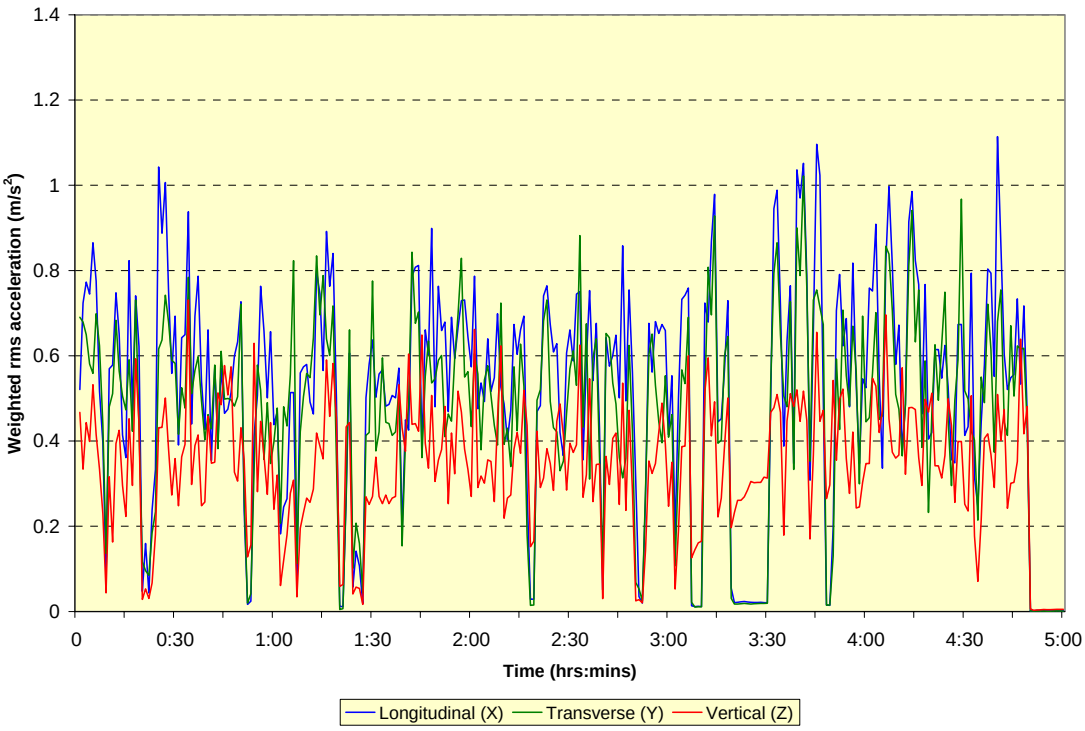

Figure A1.8.3 CAT 950F II articulated loading shovel:- time histories of weighted 1-minute rms seat accelerations (X, Y and Z-axes)

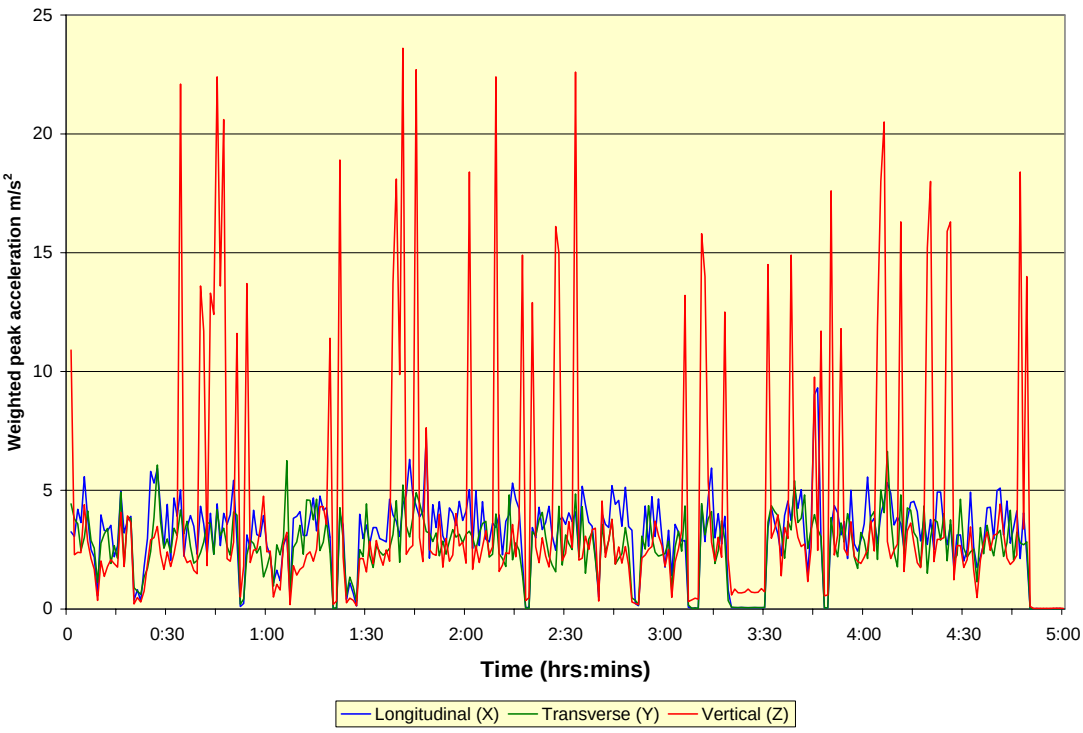

Figure A1.8.4 CAT 950F II articulated loading shovel:- time histories of weighted 1-minute peak seat accelerations (X, Y and Z-axes)

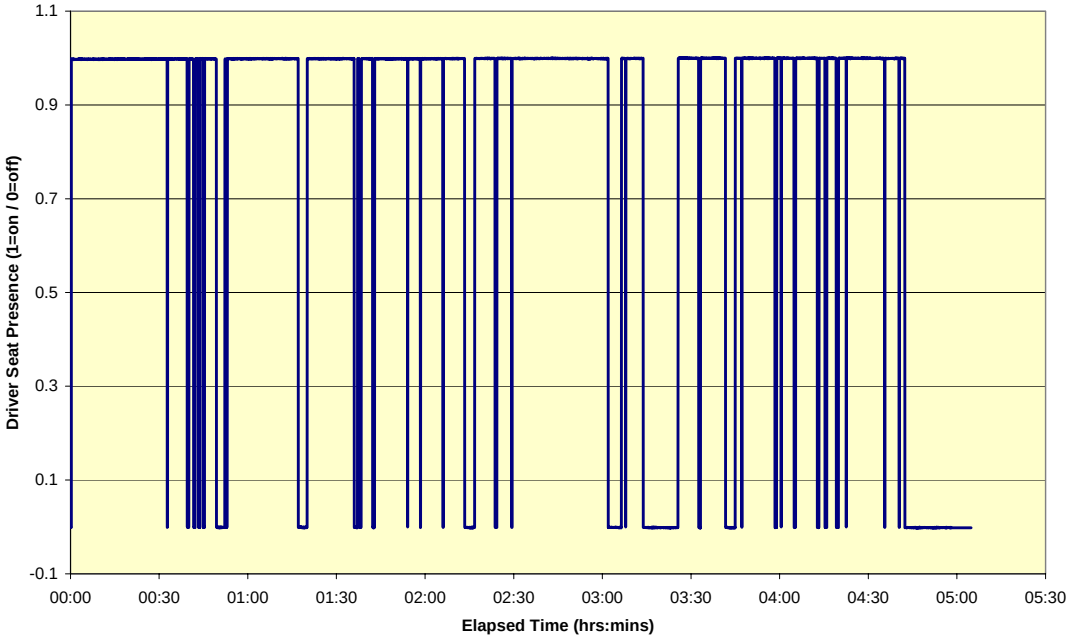

Figure A1.8.5 CAT 950F II articulated loading shovel:- driver seat presence time history

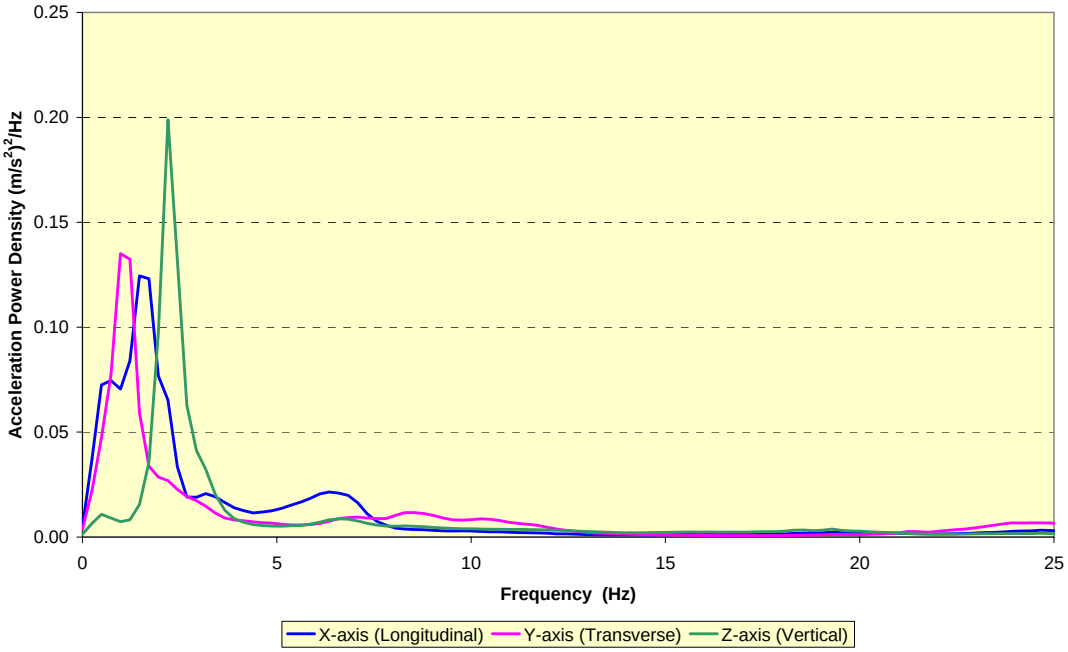

Figure A1.8.6 CAT 950F II articulated loading shovel:- acceleration power spectral density (seat)

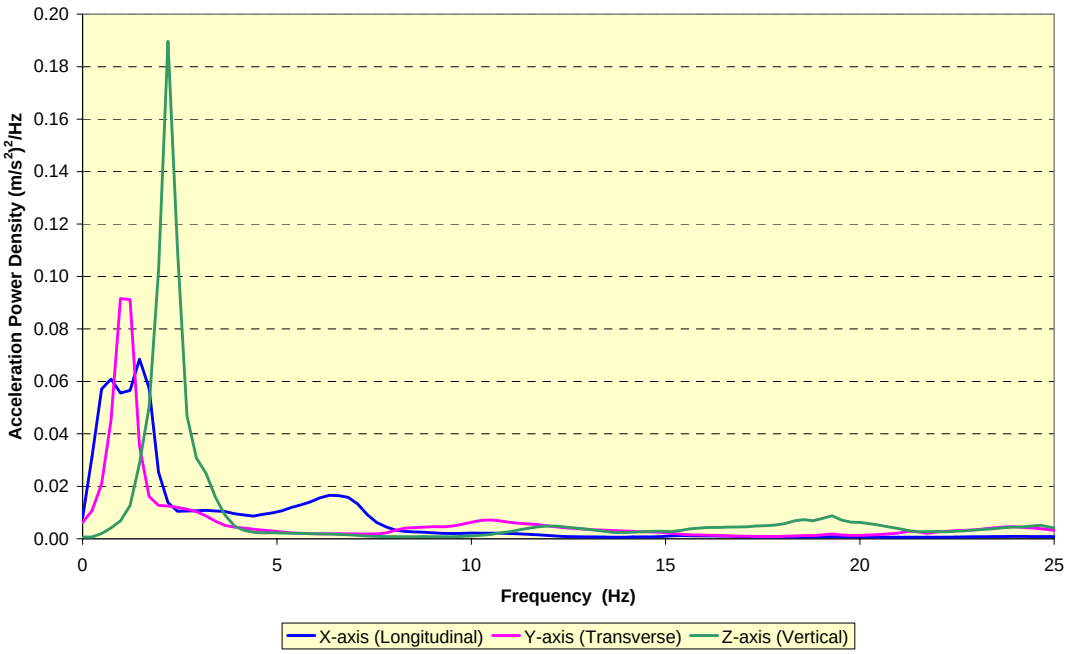

Figure A1.8.7 CAT 950F II articulated loading shovel:- acceleration power spectral density (floor)

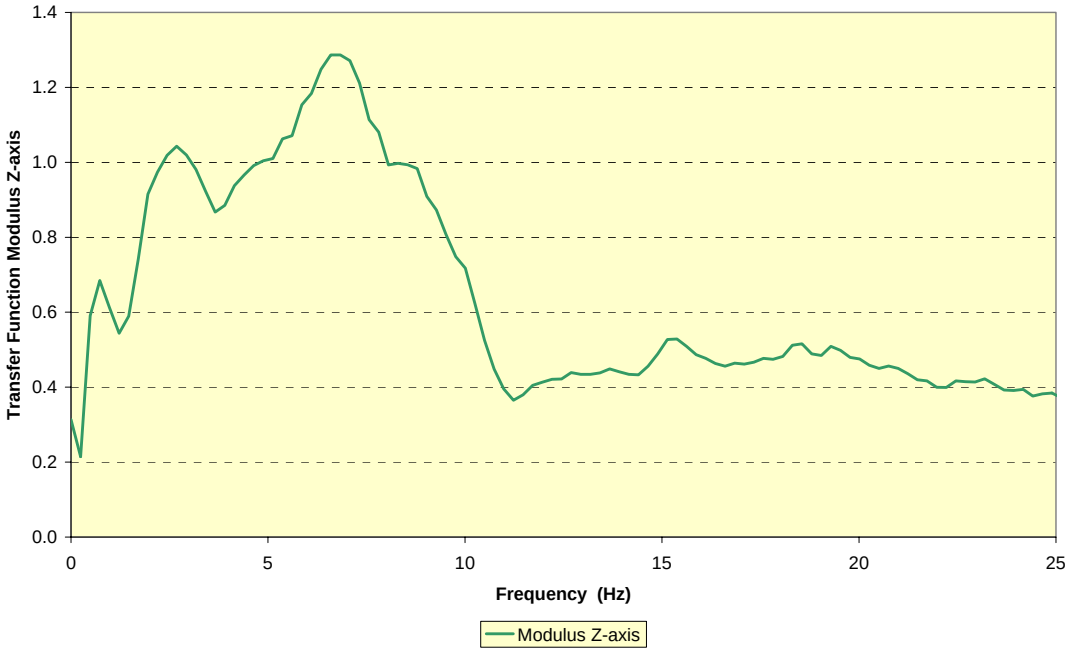

Figure A1.8.8 CAT 950F II articulated loading shovel:- seat transfer function – Magnitude

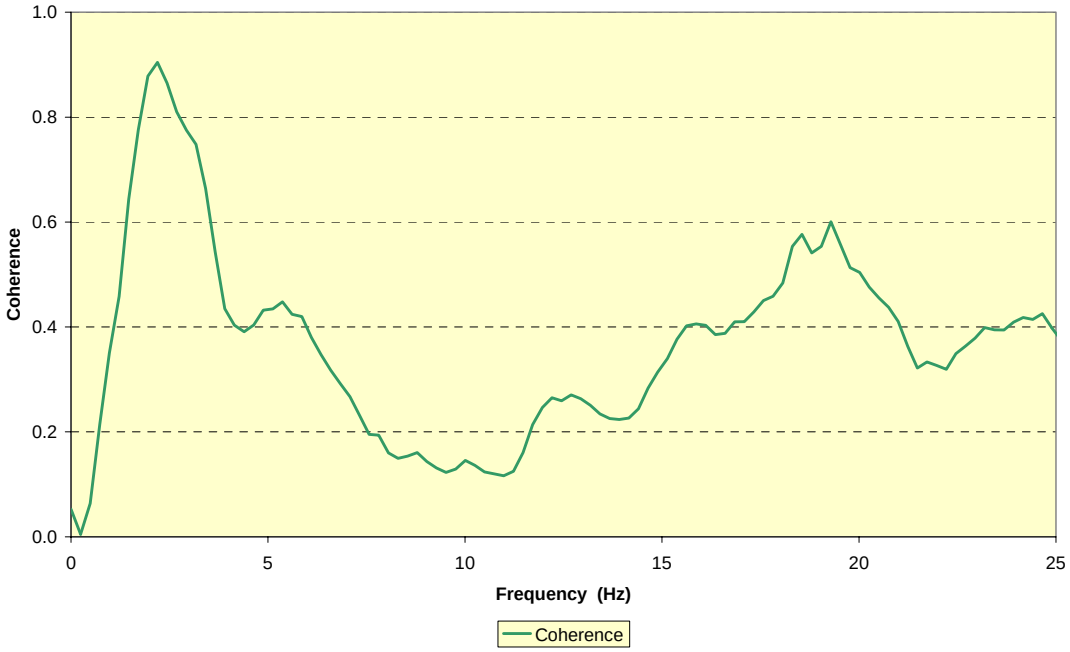

Figure A1.8.9 CAT 950F II articulated loading shovel:- seat transfer function – Coherence

Appendix 1.9: Machine No.9 – Caterpillar 970F Articulated Loading Shovel

A1.9.1 Operational Details

Date: Tuesday 7th December 2004

Location: UK Coal Mining Ltd.,
Maltby Colliery
Maltby
South Yorks

Machine Make: Caterpillar 970F articulated loading shovel, fitted with 6 tonne capacity "toe-tip" bulk materials bucket, on coal loading duties.

Model: 970F

P.I.N.: 9KJ00688
Operating mass: 237780 kg
Built: 1996
Engine power: 187 kW
Recorded engine hours: 33013 hrs
Wheelbase: 3.4 m
Wheel track: 2.2 m
Tyre width: 0.65 m

	Front	**Rear**
Tyre size(s):	26.5 R25 Michelin tubeless radial	As front
Tyre pressure:	5 bar (L & R)	2.5 bar (low)(L) 4.2 bar (R)

Operator's name: John: experienced, conscientious, but very swift
Weight: 94 kg

M/C Chassis: Vertically - rigid articulation joint
- Rigidly mounted front axle: Centrally - pivoting rear axle

Vehicle Suspension: None

Seat Suspension: KAB525 Mechanical scissor-type spring and damper, Z axis high-back suspension seat, fitted with arm rests. Lap belt fitted, but not worn by operator.

Seat condition: Good: - a replacement seat fitted within last 2 months following age -related failure of previous example. Seat adjustment OK, though possibly somewhat soft for operator's mass.

Instrumentation: Seat:- PCB 356B40 in seat pad plus operator seat presence switch
Floor:- SRI Tri-axial Floor Box No. 3 attached to seat mounting

Site Operation:- Machine used for general material (coal) loading duties all round the colliery pit head, 24 hrs/day over 2 x 12 hr shifts. One of a team of approx. 6 loading shovels, some larger, some smaller. Normal weekly operation comprises:-

- Feeding / removing material from barrel screening machines;
- Loading lorries with screened material;
- Loading 1200 tonnes of coal into railway wagons twice per week.

Measurement Period:- ~2 ½ hrs loading a train comprising 17 wagons (72 tonnes/wagon –1200 tonnes total) - remainder feeding emptying screening m/c and loading artic lorries.

Operational Record:-

07.20	**0:00**	Data recording started. Machine stationary - awaiting arrival of rail transport for loading to commence from stockyard.
07.23	**0:03**	Operator enters cab and begins loading operation.
07.41	**0:21**	Two railway wagons loaded starting on the third.
07.48	**0:48**	Three wagons loaded. Train moving forward. Loader stationary awaiting train to move forward, empty wagons so it can begin to load them.
07.49	**0:29**	Loading recommences wagon 4.
07.59	**0:39**	Begin loading wagon 5
08.06	**0:46**	Wagon 5 complete begins loading Wagon 6. Shuttling distances are now much shorter because Wagon. 6 is positioned right beside the heap.
08.13	**0:53**	Wagon 6 completed.
08.14	**0:54**	Waiting for train to move forward
08.14	**0:54**	Begins loading Wagon 7.
08.24	**1:04**	Wagon 7 completed begin loading wagon 8
08.31	**1:11**	Begin loading wagon 9.
08.38	**1:18**	Completed loading wagon 9. Beginning wagon 10. Possible to do this now without moving train, given that stockpile has decreased in size and access is now possible to the rear of the train.
08.42	**1:22**	Pausing momentarily while train moves forward in stockyard
08.42+	**1:22+**	Loading recommences
08.47	**1:27**	Wagon 10 completed
08.54	**1:34**	Wagon 11 completed begin loading wagon 12
09.02	**1:42**	Operator rest break, machine stops momentarily and operators swap John goes to have rest, while new younger operator comes to drive machine. This is half way through loading Wagon 12.
09.04	**1:44**	New operator begins loading Wagon 13 **Comment:** new operator appears to be slightly less experienced and slightly less confident in operation of machine; takes things more gently especially when tipping into wagons.
09.13	**1:53**	Completed loading Wagon 13 begins loading Wagon 14. Comment: rail wagons approximately 20 m long
09.22	**2:02**	Finishes loading wagon 14 begins loading Wagon 15.
09.30	**2:10**	Completed loading wagon 15. Waiting for train to move forward to begin loading wagon 16
09.32	**2:12**	Begins loading wagon 16
09.32	**2:12**	Replacement operator leaves cab John returning from tea break
09.33	**2:13**	John returns to cab and continues operating loading wagon 16 **Comment:** Operating technique of replacement operator equalled that of original operator after approximately 5-10 minutes into the replacement period.
09.40	**2:20**	Begins loading wagon 17.
09.46	**2:26**	Completed loading wagon 17, completed loading train.
09.48	**2:28**	Train loading completed: checked operation of data acquisition equipment.
09.53	**2:33**	Change of Operation:- moving material from one stockpile to another
10.00	**2:40**	Completes stockpile shifting, leaves stockpile area and goes to load lorry..

10.03	**2:43**	Begins loading artic lorry from stockpile in separate yard.
10.06	**2:46**	Completes loading artic lorry.
10.07	**2:47**	Begins to load screening machine, separating coal into different fractions.
10.10	**2:50**	Begins to load second artic lorry from stockpile on coal surface.
10.14	**2:54**	Completed loading artic lorry. Returns to feeding screening machine
10.25	**3:05**	Feeding screening machine & moving material around stockpile yard
10.25 to 10.37	**3:05 – 3:17**	Moving material from barrel screen cleaner to stockpile approximately 200 m away via a concrete track. Just return travel loaded one direction and unloaded the other.
10.40	**3:20**	Operator stops vehicle and gets out of cab to clean cab windows.
10.43	**3:23**	Operator returns to cab and starts moving again. Moving material from barrel screen cleaner to adjacent stockpile.
11.03	**3:43**	Driver stops and gets out of cab to inspect nearby dump truck
11.06	**3:46**	Operator re-enters cab and moves shovel towards car for removal of instrumentation.
11.11	**3:51**	Data acquisition equipment stopped.

Operational Comments:-

Loading Train:- **Data Analysis Period:- 0:04 – 1:43 hrs Analysis Duration:- 1:40 hrs:mins**

- Operation involves V-shaped loading cycle from heap into train located on left hand side of stockyard. Initial wagon position involves long travel distances from heap to load tip area: consequently machine reaches speeds of up to 12, 14 even possibly 16 km/h unladen when running back to the heap to pick up another bucketful. Operating speeds are marginally lower when bucket is loaded.
- Stockyard has a relatively smooth concrete surface, apart from the extremities of the loading pad. Surface broken up in places with some quite severe depressions up to 30 cm deep, but these have been smoothed off by deposition of coal in them. Overall surface is therefore moderate to good for a very large wheeled machine such as the loading shovel in question
- Driver's operating technique is smooth, but extremely rapid, assisted by relatively level surface of stockyard. Operator user loader bucket to scrape surface of the yard intermittently during loading cycles.
- Material being loaded is extremely fine, dry coal. Approximately three wagons can fit in the length of the loading yard: : appears to take approximately 10 minutes to load a wagon (72 tonnes).
- The relatively soft, fine nature of coal being loaded reduces the impact upon the loading shovel as it drives into the heap, decelerating it relatively smoothly with no jerks bumps or shocks to the operator.
- Only shocks that appear to be apparent are when the operator crowds the bucket back upon leaving the heap which causes a vertical shock to go through the machine and the rear of the machine to raise up as load is transferred on to the loading arms.
- At times the enthusiastic operator manages to raise the rear wheels of the machine off the ground as the load is extracted from the heap. However, this does not seem to add significantly to the level of vibration experienced, being performed in a relatively flowing manner.

General Stockpile Yard Loading & Transfer Duties:-

Data Analysis Period:- 2:28 – 3:43 hrs Analysis Duration:- 1:16 hrs:mins

- **Stockpile Transfer:-** V-shaped operation from one stockpile to another. When discharging operator drives into stockpile with bucket fully raised and uses toe-tip bucket to achieve necessary heap of stock. Approx. 50 m between stockpiles. Stockpile yard area completely flat concrete surface;
- **Loading Lorries:-** Loading 38-tonne articulated lorries with screened coal;
- **Feeding Screening Machine:-** Filling feed hopper of screening machine and moving material from machine discharge heaps to storage stockpiles.

Figure A1.9.1 CAT 970F articulated loading shovel loading rail wagons with coal (1200 tonnes) and performing stockpile yard duties

A1.9.2 CAT 970F Articulated Loading Shovel Data:- Loading Rail Wagons

Larson Davis HVM100	SN:00215	Day	Month	Year
Location:	***Floor***	***7***	***12***	***2004***
Machine:	Caterpillar Artic. Loading Shovel			
Model No:	970F		Start time:	07:24
Task:	Loading rail wagons with coal			
Place:	Maltby Colliery, S.Yorks			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
01:40	**14.3**	**8.6**	**8.1**	**18.5**
8-hr est tot	*21.1*	*12.7*	*12.0*	*27.4*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.83	***0.60***	***0.50***	***1.14***

Estimated values	**VDV**	**rms/A(8)**
Time to EAV (hr):	0.3	2.9
Time to ELV (hr):	7.8	15.3

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
9.09	6.02	11.30	11.50

Larson Davis HVM100	SN:00272	Day	Month	Year
Location:	***Seat***	***7***	***12***	***2004***
Machine:	Caterpillar Artic. Loading Shovel			
Model No:	970F		Start time:	07:24
Task:	Loading rail wagons with coal			
Place:	Maltby Colliery, S.Yorks			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
01:40	**15.8**	**10.7**	**9.6**	**21.4**
8-hr est tot	*23.4*	*15.8*	*14.2*	*31.6*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.96	***0.75***	***0.58***	***1.35***

Estimated values	**VDV**	**rms/A(8)**
Time to EAV (hr):	0.2	2.2
Time to ELV (hr):	5.2	11.5

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
10.09	7.91	13.80	14.20

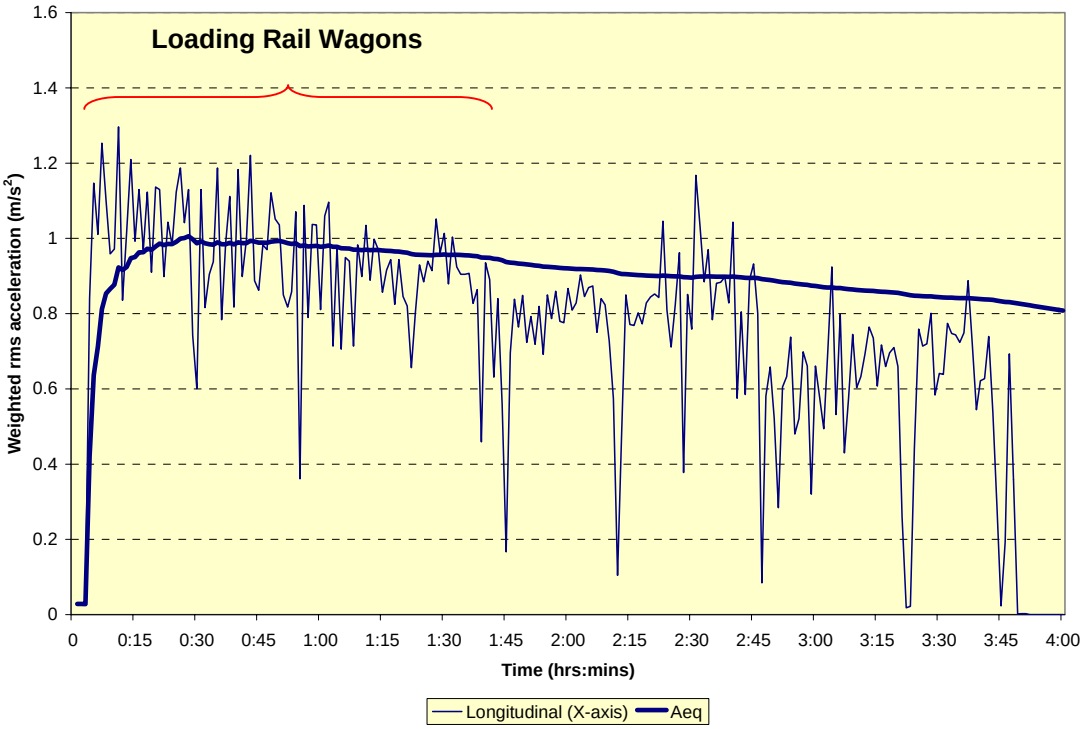

Figure A1.9.2 CAT 970F articulated loading shovel:- time history of weighted 1-minute rms seat accelerations (X-axis) and equivalent continuous rms acceleration (Aeq) – entire recording period

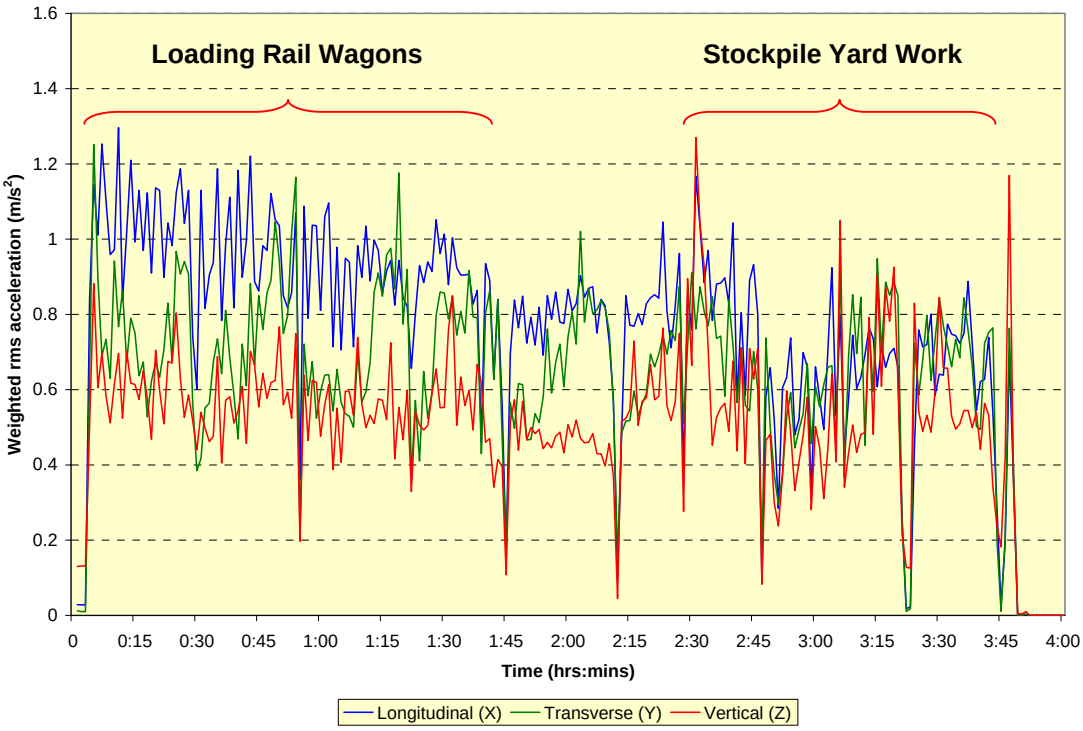

Figure A1.9.3 CAT 970F articulated loading shovel:- time histories of weighted 1-minute rms seat accelerations (X, Y and Z-axes) – entire recording period

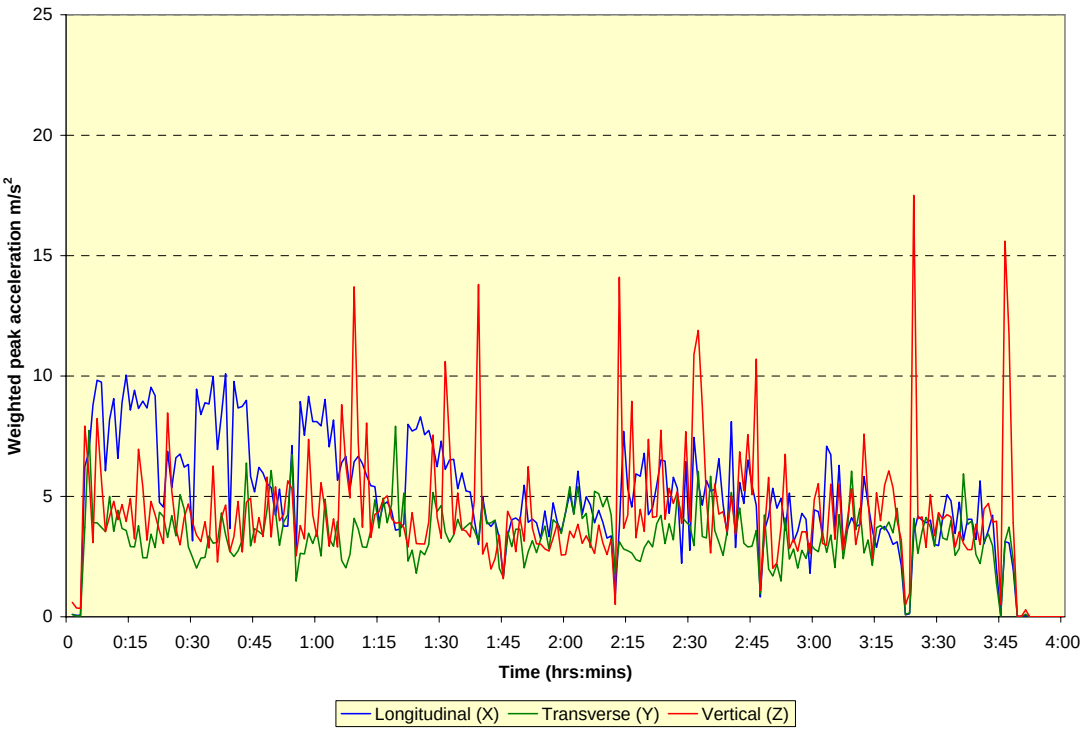

Figure A1.9.4 CAT 970F articulated loading shovel:- time histories of weighted 1-minute peak seat accelerations (X, Y and Z-axes) – entire recording period

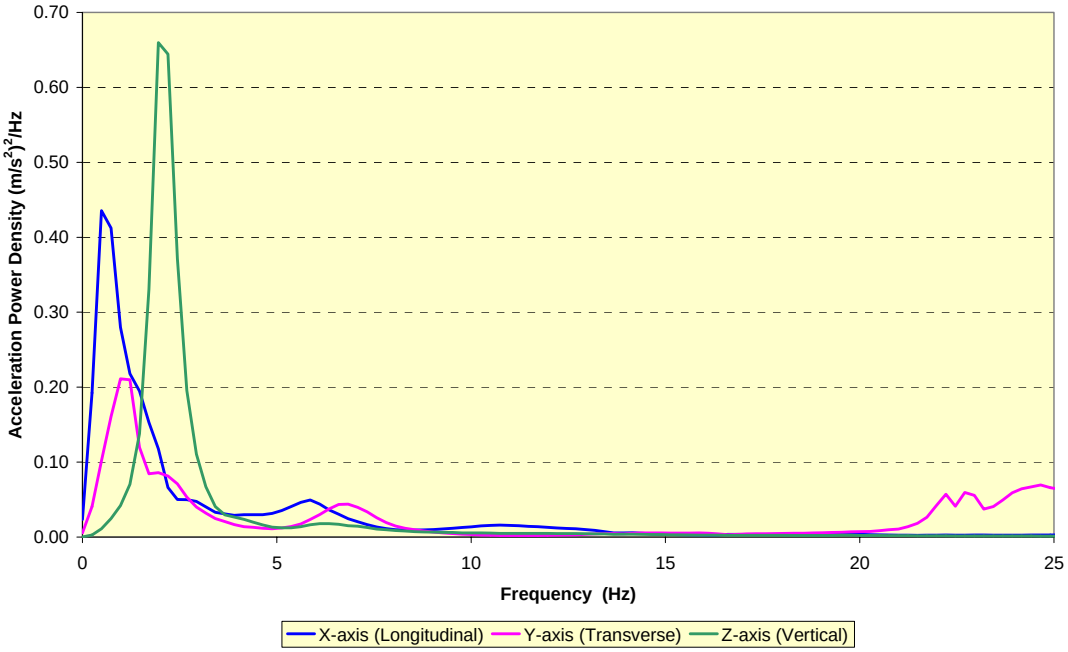

Figure A1.9.5 CAT 970F articulated loading shovel:- acceleration power spectral density (seat) – whilst loading rail wagons

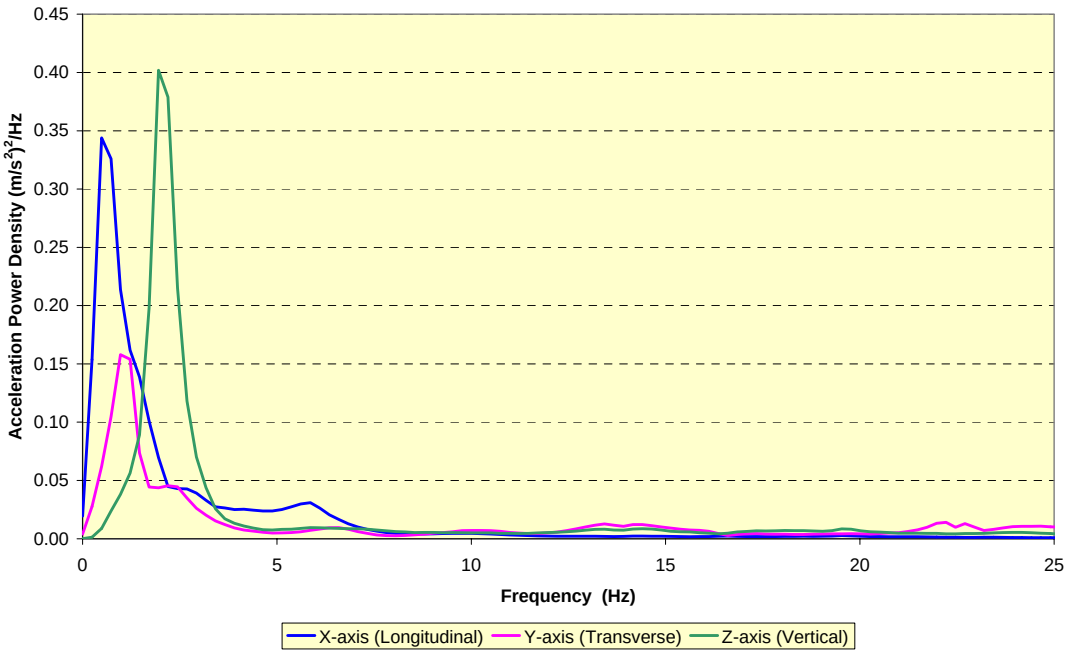

Figure A1.9.6 CAT 970F articulated loading shovel:- acceleration power spectral density (floor) – whilst loading rail wagons

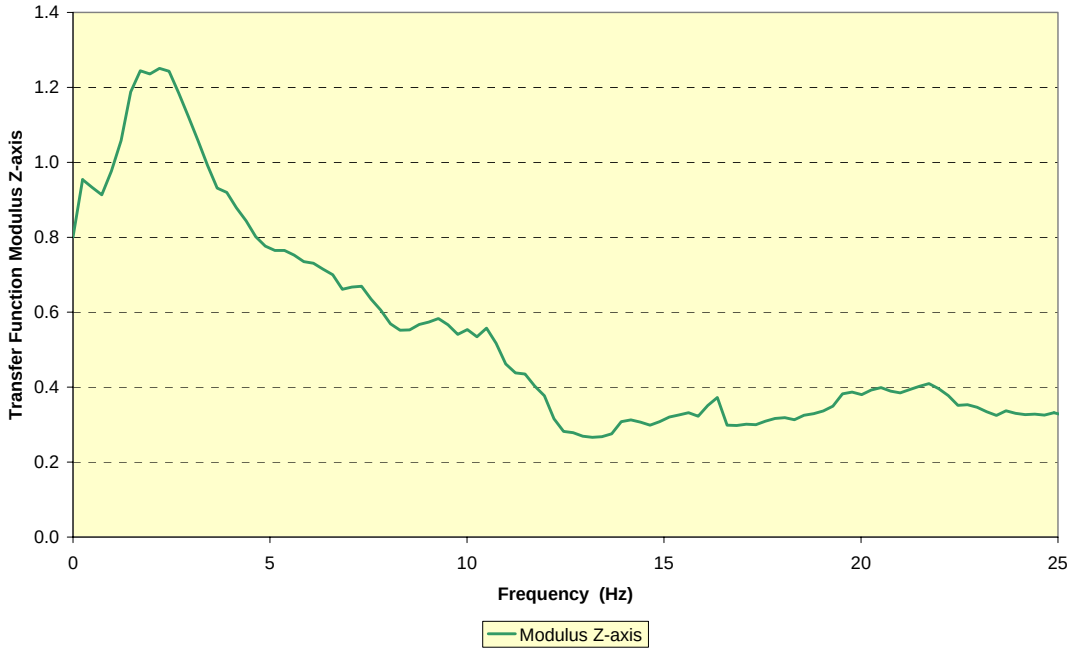

Figure A1.9.7 CAT 970F articulated loading shovel:- seat transfer function – Magnitude – whilst loading rail wagons

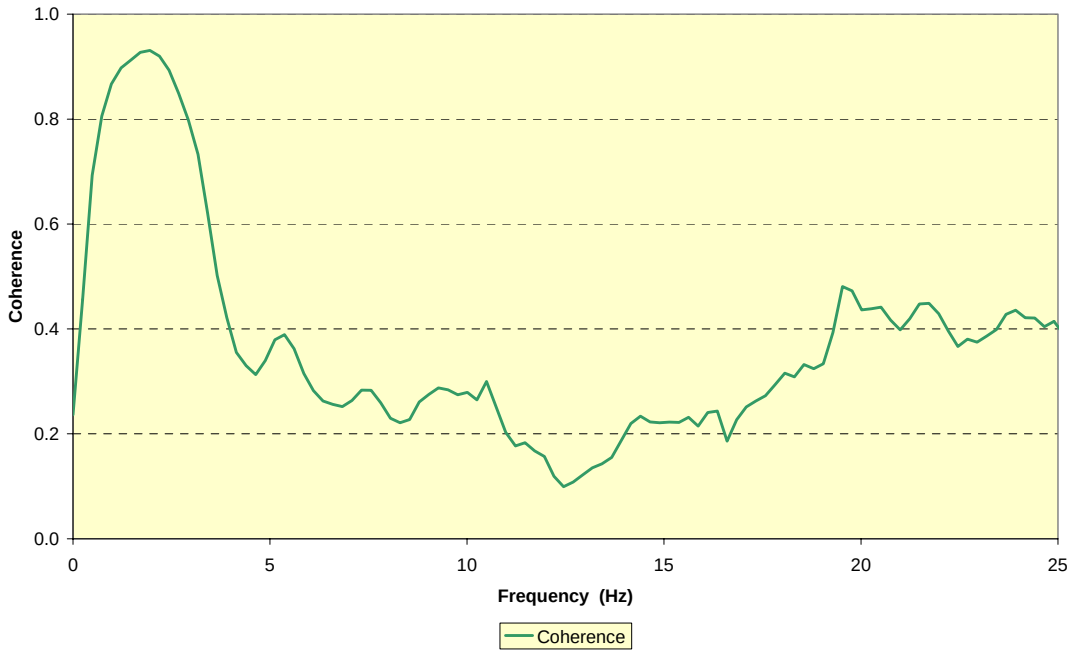

Figure A1.9.8 CAT 970F articulated loading shovel:- seat transfer function – Coherence – whilst loading rail wagons

A1.9.3 CAT 970F Articulated Loading Shovel Data:- Stockpile Yard Work

Larson Davis HVM100	SN:00215	Day	Month	Year
Location:	***Floor***	***7***	***12***	***2004***
Machine:	Caterpillar Artic. Loading Shovel			
Model No:	970F		Start time:	09:48
Task:	General Yard Work			
Place:	Maltby Colliery, S.Yorks			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
01:16	**9.1**	**7.3**	**7.8**	**14.0**
8-hr est tot	*14.3*	*11.6*	*12.4*	*22.2*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.60	***0.54***	***0.47***	***0.93***

Estimated values	**VDV**	**rms/A(8)**
Time to EAV (hr):	1.3	5.6
Time to ELV (hr):	36.7	29.8

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
7.49	5.80	12.80	13.20

Larson Davis HVM100	SN:00272	Day	Month	Year
Location:	***Seat***	***7***	***12***	***2004***
Machine:	Caterpillar Artic. Loading Shovel			
Model No:	970F		Start time:	09:48
Task:	General Yard Work			
Place:	Maltby Colliery, S.Yorks			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
01:16	**10.5**	**9.0**	**10.5**	**17.4**
8-hr est tot	*16.6*	*14.2*	*16.7*	*27.5*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.70	***0.67***	***0.59***	***1.13***

Estimated values	**VDV**	**rms/A(8)**
Time to EAV (hr):	0.7	4.1
Time to ELV (hr):	20.0	21.7

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
8.11	6.05	17.50	17.40

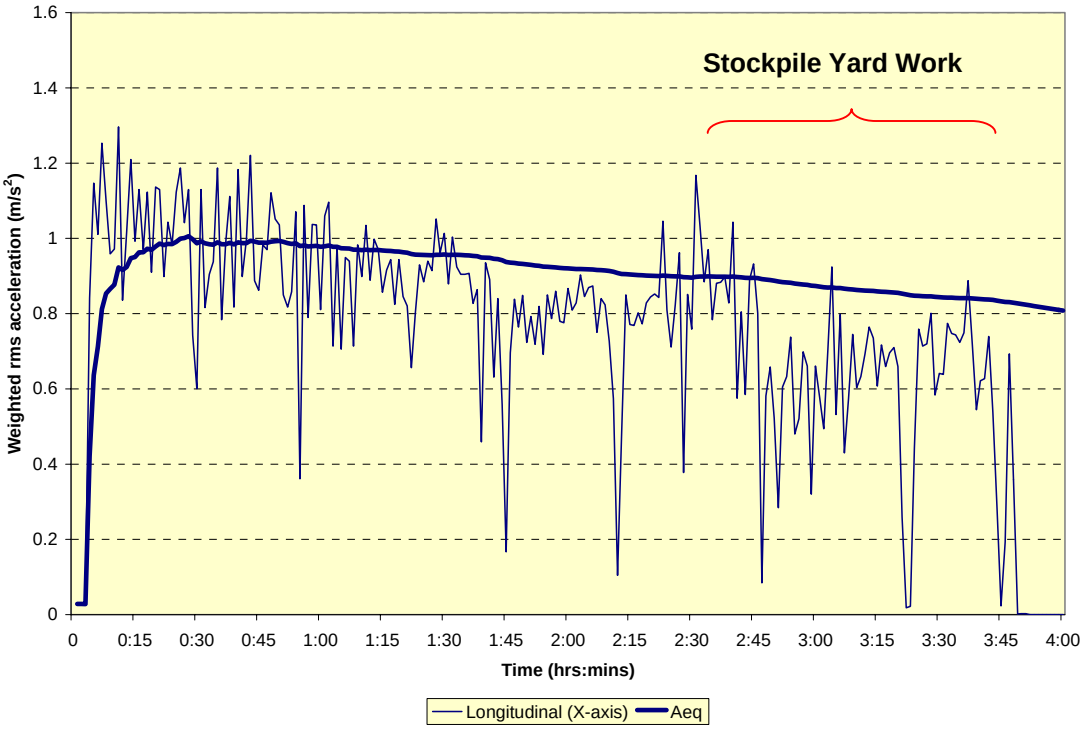

Figure A1.9.9 CAT 970F articulated loading shovel:- time history of weighted 1-minute rms seat accelerations (X-axis) and equivalent continuous rms acceleration (Aeq) – entire recording period

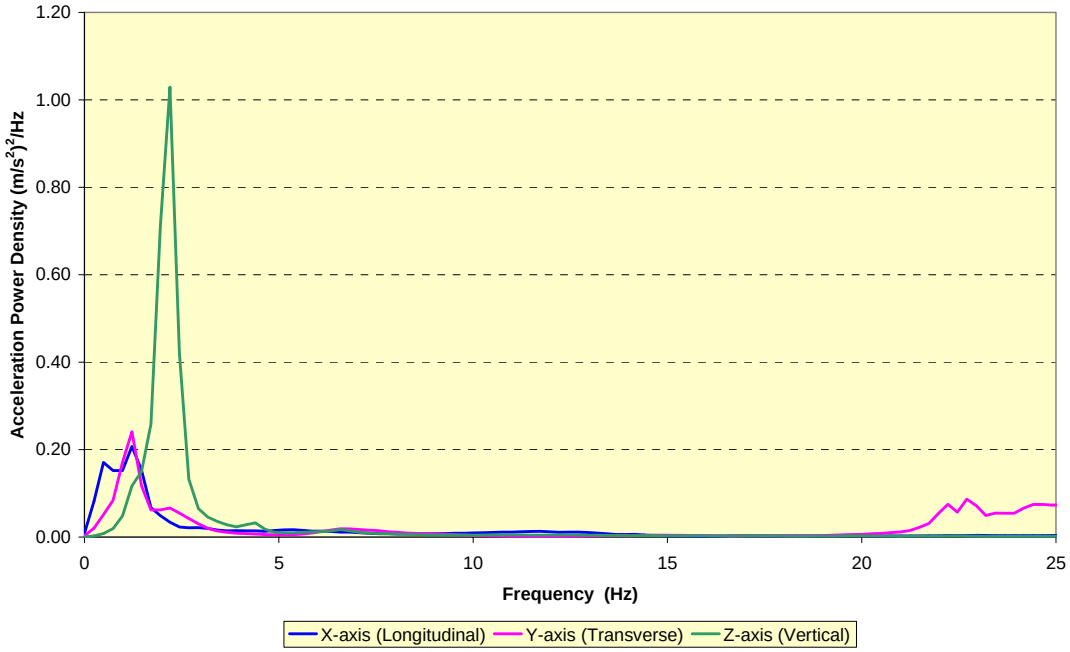

Figure A1.9.10 CAT 970F articulated loading shovel:- acceleration power spectral density (seat) – whilst performing general yard work

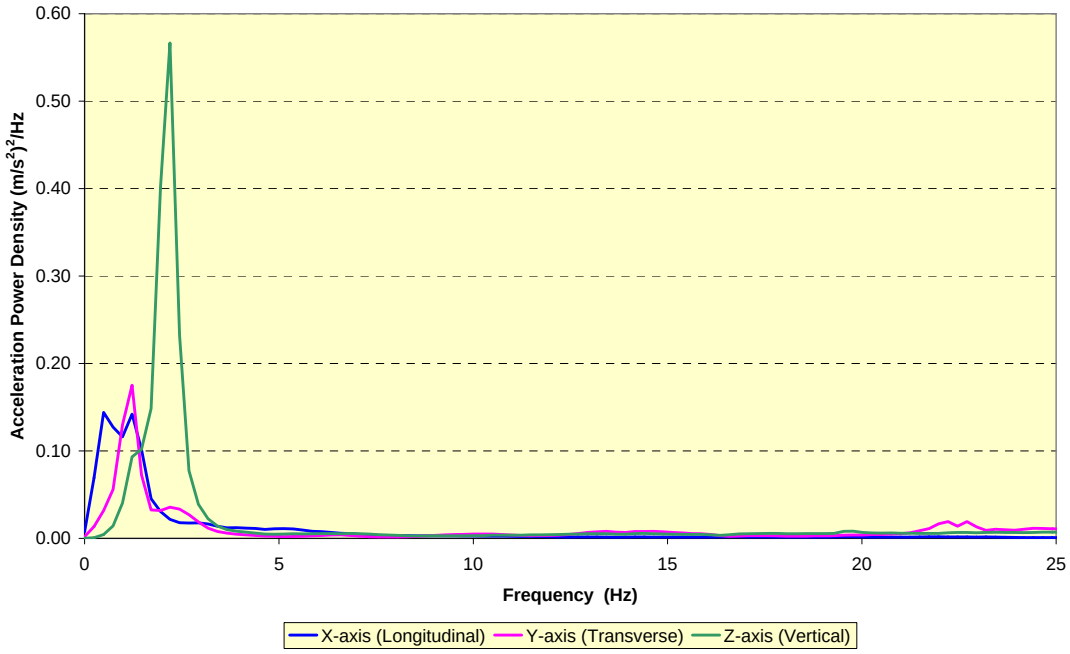

Figure A1.9.11 CAT 970F articulated loading shovel:- acceleration power spectral density (floor) – whilst performing general yard work

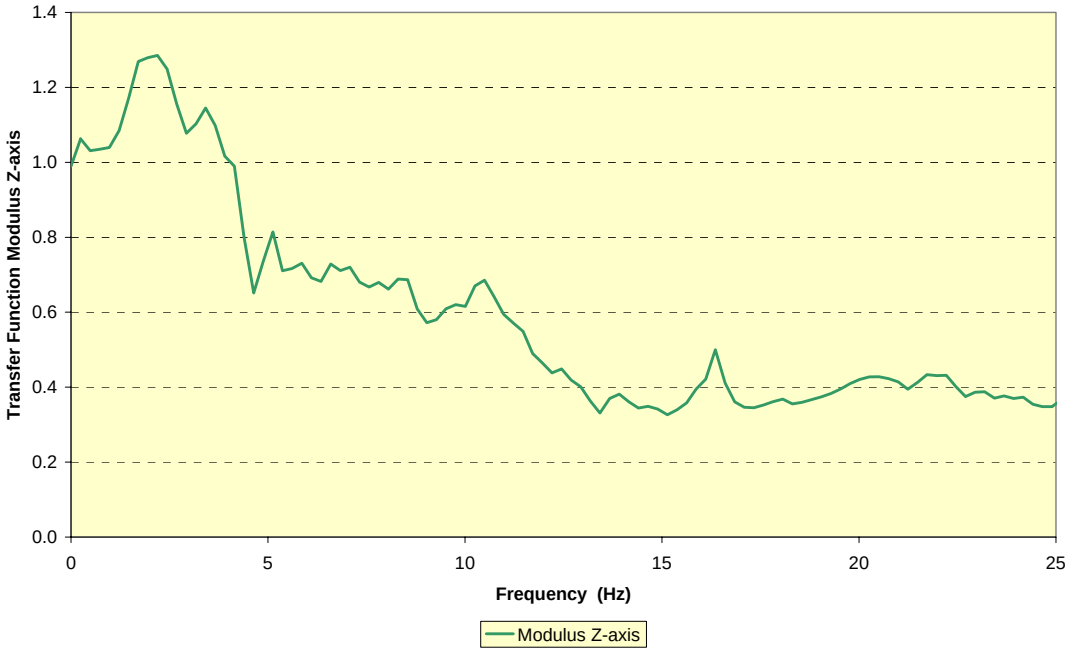

Figure A1.9.12 CAT 970F articulated loading shovel:- seat transfer function – Magnitude – whilst performing general yard work

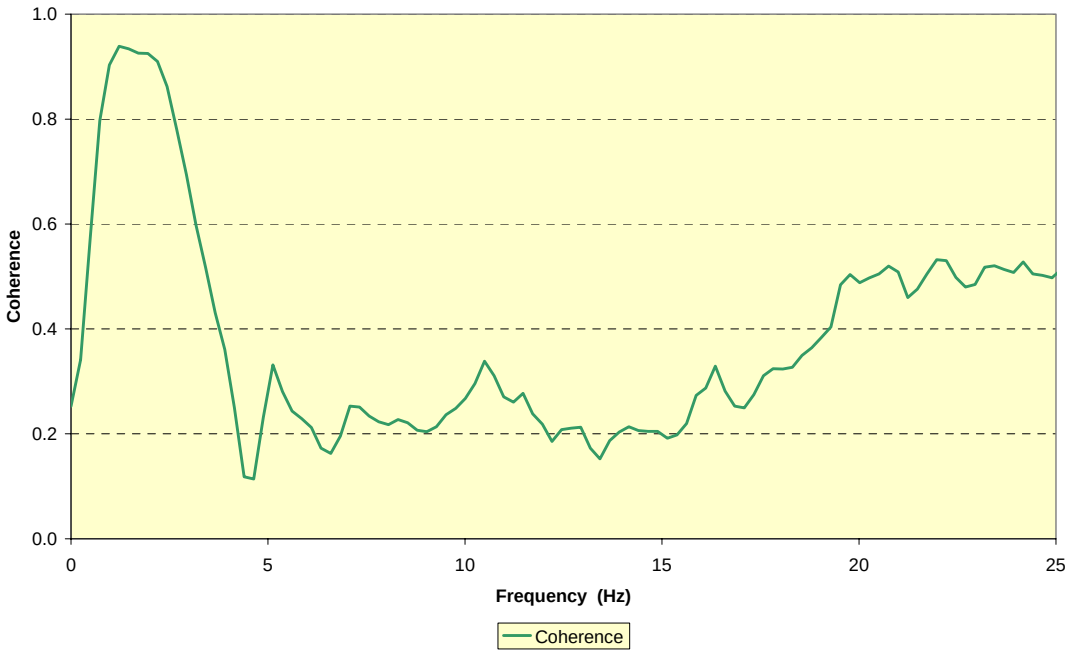

Figure A1.9.13 CAT 970F articulated loading shovel:- seat transfer function – Coherence – whilst performing general yard work

Appendix 1.10: Machine No.10 – Foden 32-tonne 8-wheeled Truck

A1.10.1 Operational Details

Date: 22 September 2004

Location: Lafarge Aggregates, Mountsorrel Quarry to RAF Waddington: 30 miles of various roads between.

Machine Details:

Make:	Foden
Model:	8-wheeled rigid tipper truck
Weight:	11.5 tonne unladen
Capacity:	32 tonne laden GVW
Power:	
Registration:	
VIN/Serial No:	
Year of build:	2002
Condition:	Maintained to 'as new' standard
Tyre size/make:	
Tyre pressures:	All at 20 lb/in^2 (1.5 bar)

Vehicle Suspension:

Chassis:-	Leaf springs to front axle, rubber blocks at rear.
Cab:-	Coil springs and torsion bars

Seat Suspension: ISRI air suspension in good working order

Operated by: Owner driver (Dave Darcy), contracted to Lafarge Aggregates, Mountsorrel.

Operator: Weight 110 kg

WBV Instrumentation (transducers):

Seat:-	ICP type PCB 356B40 in seat pad plus operator seat presence switch
Floor:	ICP type PCB 356B40 attached by magnetic clamp to floor next to seat rail.

Site Operations:-

The recording covered a period of 3¼ hours, and included a single cycle of load – travel – unload – return journey.

The loading section included travel from the lorry park to the first weighbridge, manoeuvres under the loading hopper, travel to the second weighbridge, and thence via the wheel-wash to the quarry gate. The surface inside the quarry was partly smooth concrete, part slightly broken concrete, with a small number of speed humps.

The road travel from Mountsorrel to RAF Waddington (near Lincoln) comprised 9 miles of dual carriageway, 19 miles of single carriageway "A" road and about 5½ miles of suburban road, and included 14 roundabouts and 6 traffic lights. The return journey covered the same route. Travel speed when not limited by traffic of statutory limits was about 50 mph.

The unloading section included an off-road manoeuvre to avoid a right turn off a busy road, travel over smooth perimeter roadway to the tipping site, and return to the road without the off-road manoeuvre.

Analysis of the vibration from different sections of the recording should enable exposure values to be estimated for days which include more, shorter journeys, and a larger component of off-road travel.

Operational Record:-

Recording started: **09:10 hrs** **Duration:-** **3:18 hrs:mins**
Recording stopped: **12:28 hrs**

Time (hrs:mins)	Duration (hrs:mins)	Activity : Comments
09:10	**0:00**	Recorders started.
09:12	**0:02**	Loading section started
09:28	**0:18**	Leave quarry gate.
09:30	**0:20**	Join dual carriageway trunk road (A6, followed by A46).
09:50	**0:40**	Change to single carriageway (A46)
10:21	**1:11**	Interchange with A1
10:34	**1:24**	Leave A46 for suburban road
10:48	**1:38**	Join A15 (single carriageway).
10:54	**1:44**	Start unloading section by turning off road on to rough turning site (duration on rough ground 1.25 mimutes)
11:04	**1:54**	Start return journey on A15.
12:27	**3:17**	Re-enter quarry gates
12:28	**3:18**	Vehicle stopped, Recorders stopped.

Table A1.10.1 WBV values for lorry route sections

Ref	*Route Segment*	*Duration (mins)*	*RMS weighted m/s/s, with x1.4 multiplier*					
			Seat			*Floor*		
			X	*Y*	*Z*	*X*	*Y*	*Z*
	Overall values	199	0.16	0.25	0.43	0.18	0.20	0.43
A	All inside plant	14.00	0.21	0.36	0.31	0.22	0.27	0.30
B	Lorry park to weighbridge	2.00	0.18	0.32	0.30	0.20	0.24	0.34
C	**Dual carriageway, laden (50 mph)**	16.00	0.16	0.22	**0.61**	0.17	0.19	0.58
D	Single carriageway, laden	8.00	0.15	0.25	0.48	0.16	0.20	0.46
E	New dual carriageway, laden	5.00	0.14	0.19	0.55	0.13	0.16	0.48
F	Suburban Road, laden	14.00	0.14	0.21	0.35	0.15	0.17	0.36
G	On unloading site	10.00	0.15	0.34	0.30	0.16	0.25	0.26
H	**Turning on rough ground**	1.25	0.20	**0.64**	0.47	0.24	0.47	0.43
J	Suburban Road, unladen	11.00	0.16	0.24	0.33	0.19	0.20	0.38
K	Single carriageway, unladen	13.00	0.15	0.25	0.41	0.20	0.20	0.43
L	Dual carriageway, unladen	13.00	0.19	0.21	0.51	0.21	0.18	0.52
M	Inside plant, off smooth surface	0.50	0.23	0.33	0.56	0.27	0.25	0.71

A1.10.2 Foden 32-tonne 8-wheeled Truck: Whole-Body Vibration Data

Larson Davis HVM100	SN:00385	Day	Month	Year
Location:	***Floor***	***22***	***Sep***	***4***
Machine:	Foden 8-wheeled rigid tipper truck			
Reg No:			Start time:	09:08
Task:	Deliver ballast from Mountsorrell to RAF Waddington			
Place:	Roads as above			

Total VDV ($m/s^{1.75}$)

Time	X	Y	Z	Sum
03:19	**3.8**	**3.7**	**7.2**	**8.7**
8-hr est tot	*4.8*	*4.6*	*9.0*	*10.8*

Average r.m.s. (Aeq) (m/s^2)

X	Y	Z	Sum
0.18	***0.20***	***0.43***	***0.51***

Estimated values	**VDV**	**rms/A8**
Time to EAV (hr):	8.3	10.8
Time to ELV (hr):	236.7	57.0

Maximum peak value (m/s^2)

X	Y	Z	Sum
5.08	2.76	9.15	9.17

Larson Davis HVM100	SN:00386	Day	Month	Year
Location:	***Seat***	***22***	***Sep***	***4***
Machine:	Foden 8-wheeled rigid tipper truck			
Reg No:			Start time:	09:07
Task:	Deliver ballast from Mountsorrell to RAF Waddington			
Place:	Roads as above			

Total VDV ($m/s^{1.75}$)

Time	X	Y	Z	Sum
03:19	**4.0**	**4.6**	**7.2**	**9.1**
8-hr est tot	*4.9*	*5.8*	*9.0*	*11.3*

Average r.m.s. (Aeq) (m/s^2)

X	Y	Z	Sum
0.16	***0.25***	***0.43***	***0.52***

Estimated values	**VDV**	**rms/A8**
Time to EAV (hr):	8.2	10.6
Time to ELV (hr):	233.8	56.3

Maximum peak value (m/s^2)

X	Y	Z	Sum
5.71	3.37	11.80	11.90

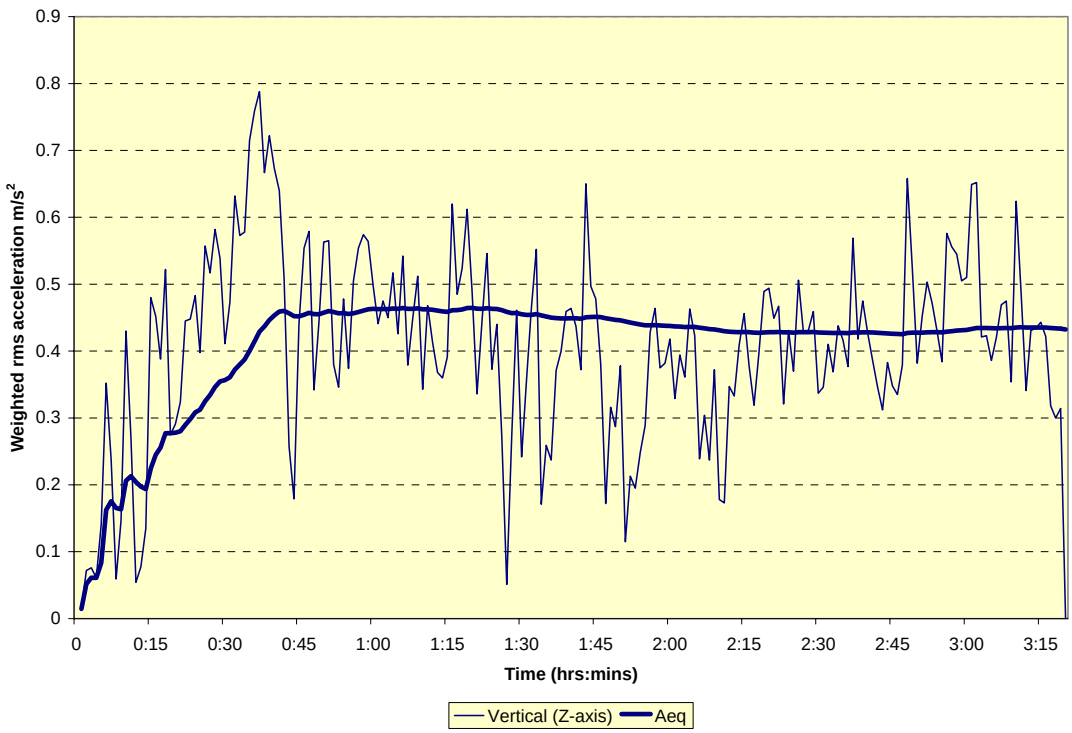

Figure A1.10.1 Foden 32-tonne 8-wheeled truck:- time history of weighted 1-minute rms seat accelerations (Z-axis) and equivalent continuous rms acceleration (Aeq)

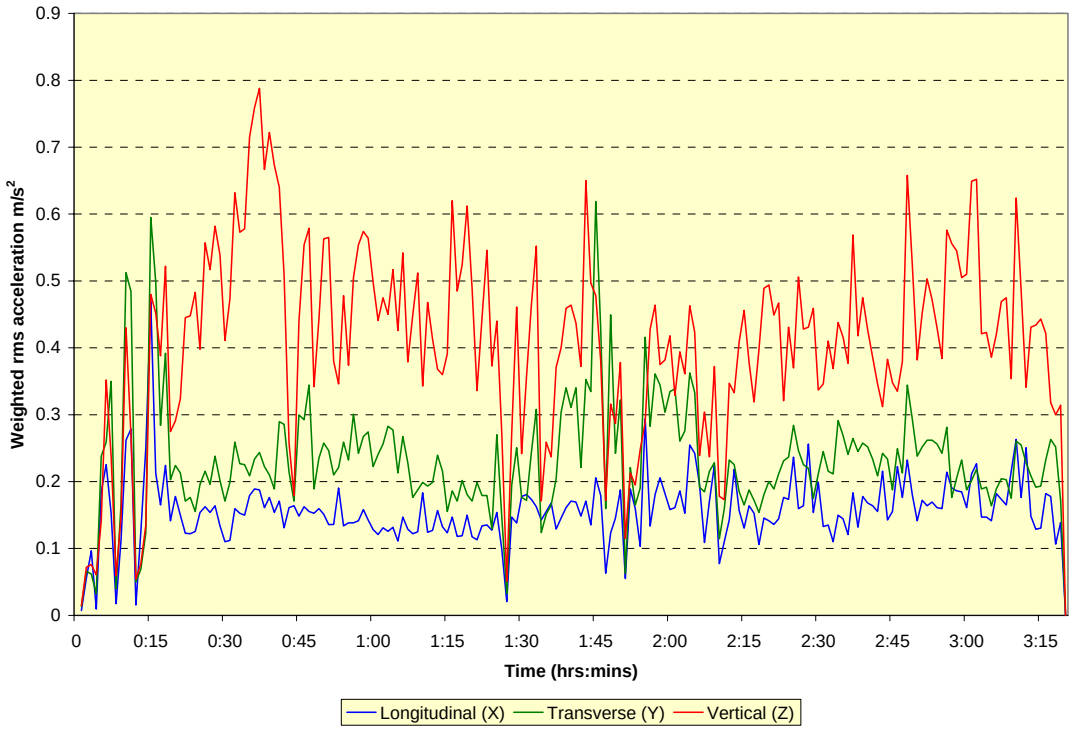

Figure A1.10.2 Foden 32-tonne 8-wheeled truck:- time histories of weighted 1-minute rms seat accelerations (X, Y and Z-axes)

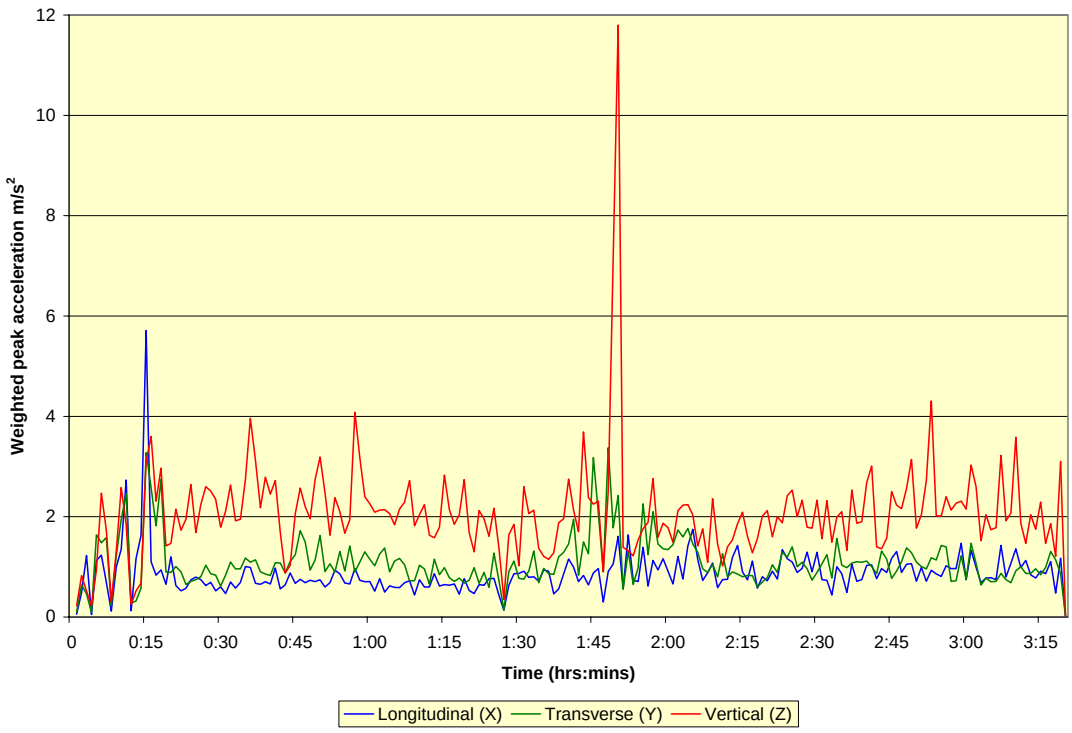

Figure A1.10.3 Foden 32-tonne 8-wheeled truck:- time histories of weighted 1-minute peak seat accelerations (X, Y and Z-axes)

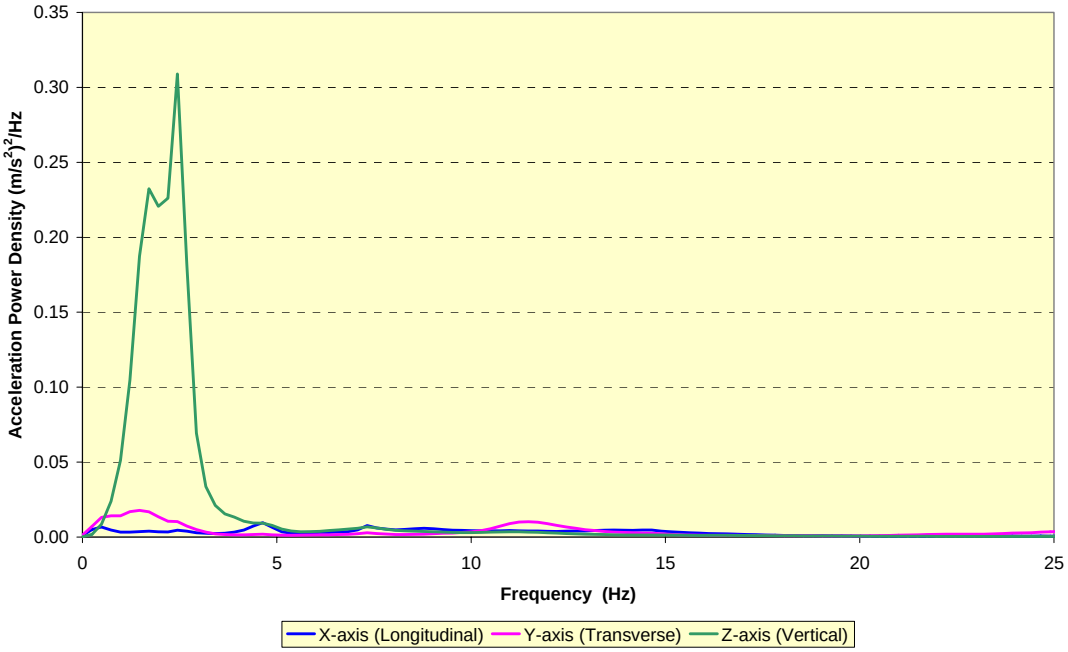

Figure A1.10.4 Foden 32-tonne 8-wheeled truck:- acceleration power spectral density (seat)

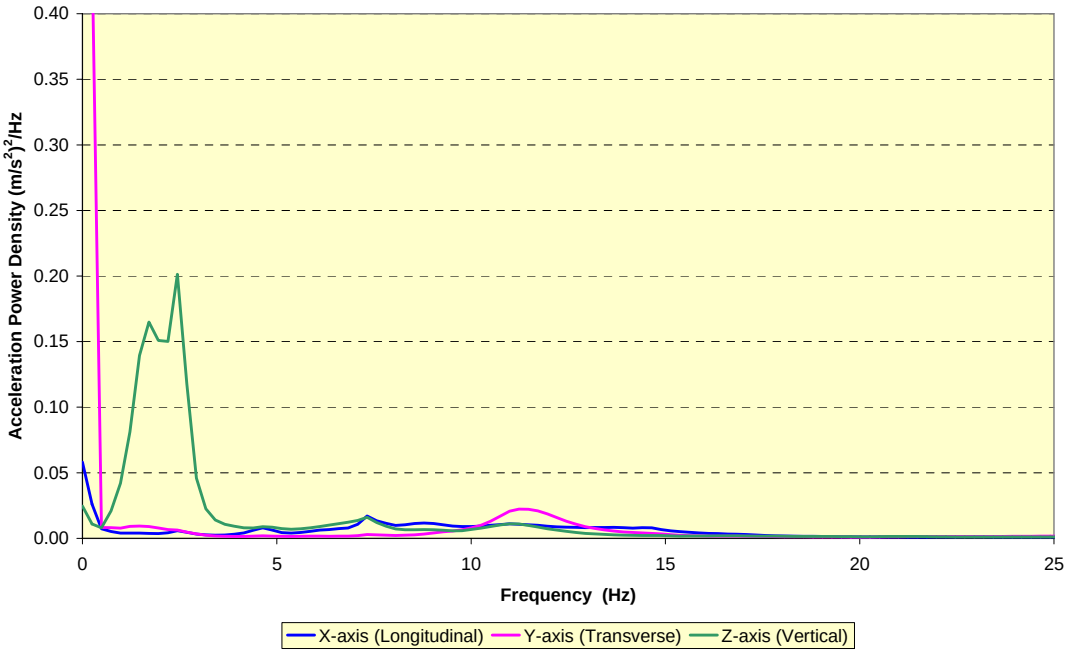

Figure A1.10.5 Foden 32-tonne 8-wheeled truck:- acceleration power spectral density (floor)

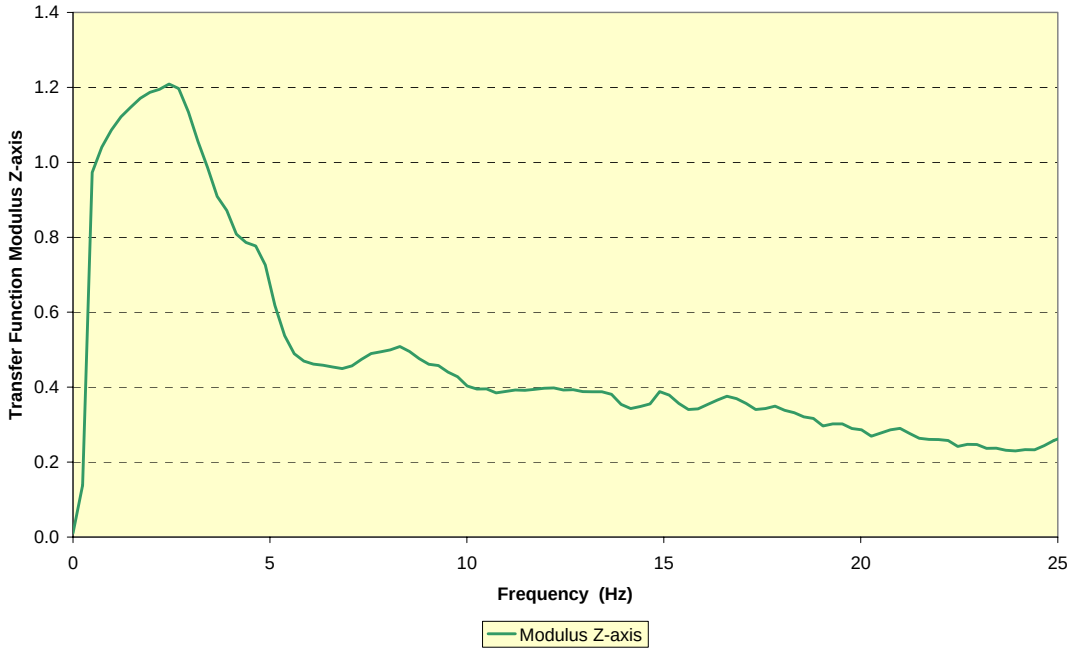

Figure A1.10.6 Foden 32-tonne 8-wheeled truck:- seat transfer function – Magnitude

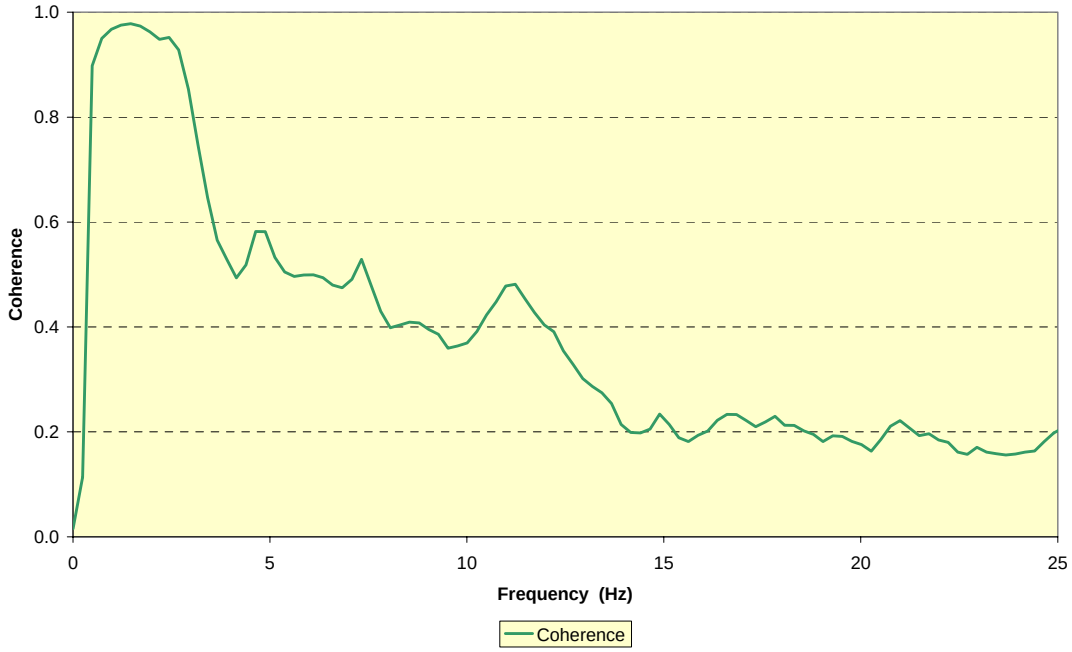

Figure A1.10.7 Foden 32-tonne 8-wheeled truck:- seat transfer function – Coherence

Appendix 1.11: Machine No.11 – Linde H25T 2.5 tonne Fork Lift Truck

A1.11.1 Operational Details

Date: 24th November 2004

Location: Aggregate Industries concrete products plant,
Hulland Ward, Near Ashbourne,
Derbyshire

Machine Details:

Make:	Linde
Model:	H25T
Weight:	3890 kg
Capacity:	2500 kg
Power:	38 kW
Registration:	Fleet No 19
VIN/Serial No:	H2X392R02914
Year of build:	2004
Condition:	Nearly new.
Tyre size/make:	Continental 23x9-10
Tyre pressures:	Front 142 lb/in^2, Rear 99 lb/in^2

Vehicle Suspension: None.

Seat Suspension: Grammer MSG85/721, compact mechanical suspension. Condition good. Set to mid-ride

Operator: Weight:- 83 kg

WBV Instrumentation (transducers):

Seat:-	ICP type PCB 356B40 in seat pad plus operator seat presence switch
Floor:	ICP type PCB 356B40 attached by magnetic clamp to floor next to seat mounting rail. **NB**:- Vertical and longitudinal axes about 10° off axis.

Site Operations:-

Measurements comprised 2 hours 50 minutes during which the truck was used to transfer a block product from the oven output inside factory "B" to storage stacks in the yard a little distance from the building. Most loads required that the driver to spend a few moments out of his seat, manipulating the load before travelling across the concrete yard. The quality of the yard surface was very variable (photograph). The site extends to 76 acres (see Fig A1.11.1). The recording period included two breaks of about 10 minutes. Direct observation of operations throughout the recording period were precluded because of the company's safety policy, which requires separation of vehicles and pedestrians. The site operates 60 lift trucks and may also have numerous lorries receiving products. Activities can only be estimated from seat presence and vibration records.

Operational Record:-

Recording started: **09:10 hrs** **Duration:-** **2:50 hrs:mins**
Recording stopped: **12:00 hrs**

Time (hrs:mins)	Duration (hrs:mins)	Activity : Comments
09:10	**0:00**	Recorders and operations started.
10.30	**1:20**	Break from operations.
10.40	**1:30**	Operations resumed.
11:25	**2:15**	Break from operations
11:35	**2:25**	Operations resumed.
11:55	**2:45**	Break from operations
12:00	**2:50**	Recorders off

Figure A1.11.1 Aerial view of Hulland Ward site

Figure A1.11.2 Operating conditions on Hulland Ward site

A1.11.2 Linde H25T 2.5 tonne Fork Lift Truck Whole-Body Vibration Data

Larson Davis HVM100	SN:00385	Day	Month	Year
Location:	***Floor***	***24***	***Nov***	***4***
Machine:	Linde H25T Lift truck			
Reg No:	H2X 39 2R02914		Start time:	09:11
Task:	Moving slabs from factory to store			
Place:	Hulland Ward factory B			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
02:45	**7.0**	**6.6**	**24.9**	**26.7**
8-hr est tot	*9.2*	*8.6*	*32.6*	*34.9*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.38	***0.35***	***1.20***	***1.31***

Estimated values	**VDV**	**rms/A8**
Time to EAV (hr):	0.0	1.4
Time to ELV (hr):	1.4	7.3

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
5.15	3.72	20.10	20.20

Larson Davis HVM100	SN:00386	Day	Month	Year
Location:	***Seat***	***24***	***Nov***	***4***
Machine:	Linde H25T			
Reg No:	H2X 39 2R02914		Start time:	09:10
Task:	Moving slabs from factory to store			
Place:	Hulland Ward factory B			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
02:45	**7.2**	**8.6**	**16.0**	**19.6**
8-hr est tot	*9.5*	*11.3*	*20.9*	*25.6*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.40	***0.45***	***0.58***	***0.84***

Estimated values	**VDV**	**rms/A8**
Time to EAV (hr):	0.3	5.9
Time to ELV (hr):	8.1	31.3

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
4.31	4.72	21.70	21.70

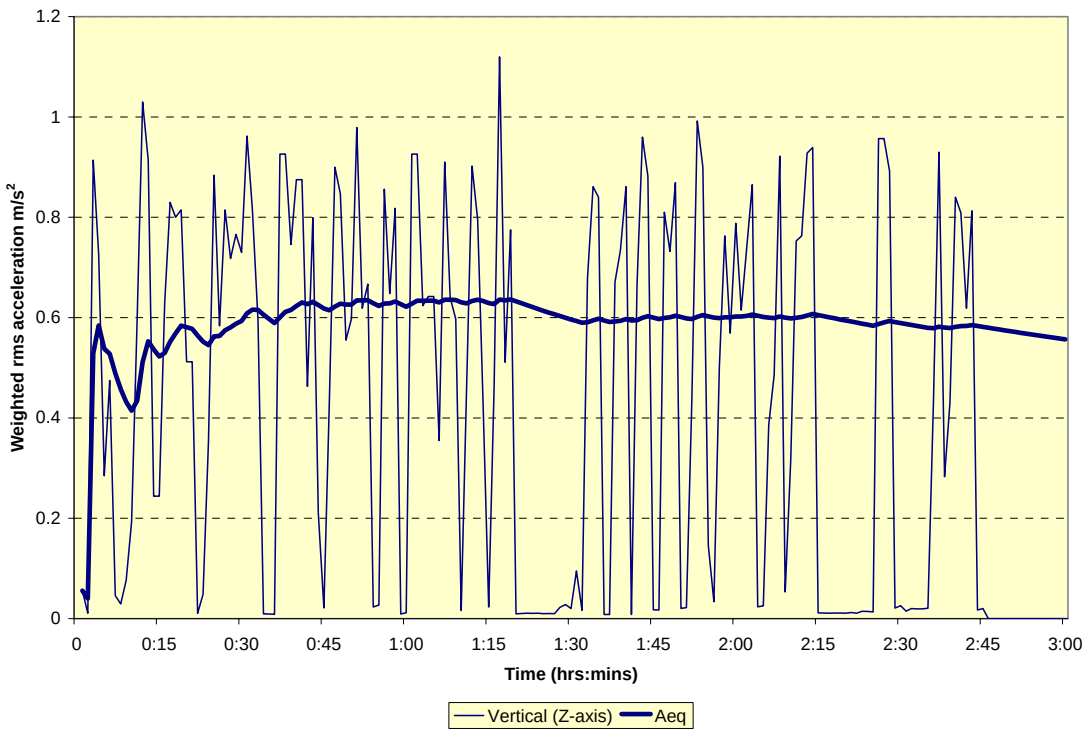

Figure A1.11.3 Linde 2.5 tonne fork lift truck:- time history of weighted 1-minute rms seat accelerations (Z-axis) and equivalent continuous rms acceleration (Aeq)

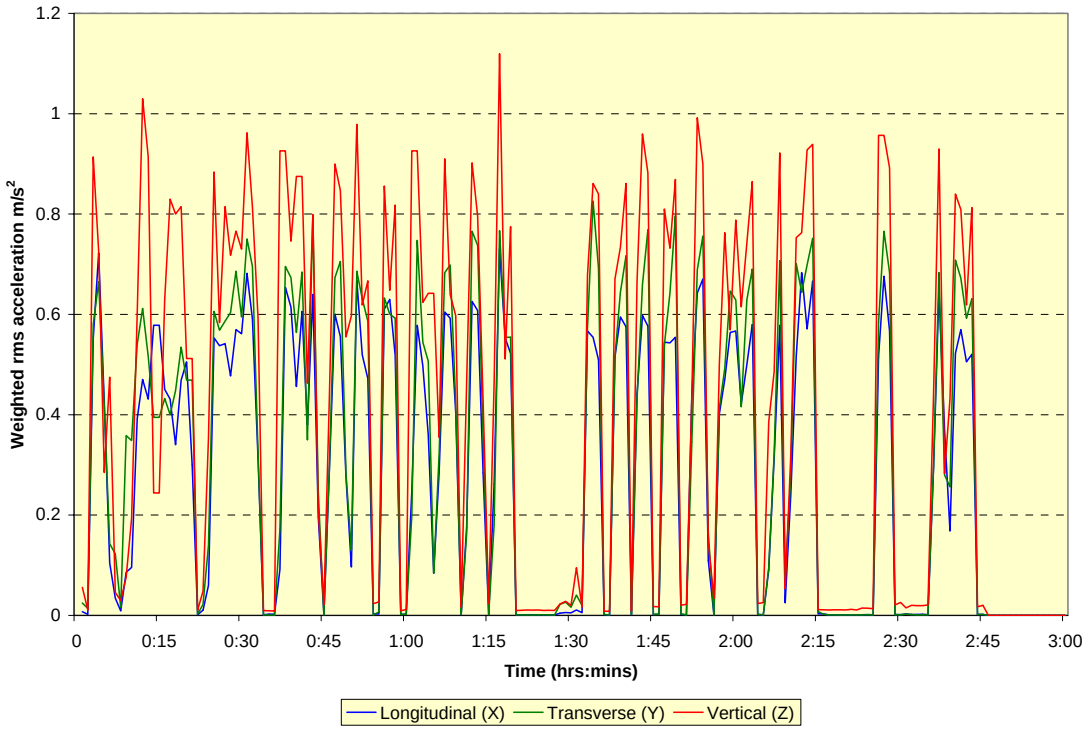

Figure A1.11.4 Linde 2.5 tonne fork lift truck:- time histories of weighted 1-minute rms seat accelerations (X, Y and Z-axes)

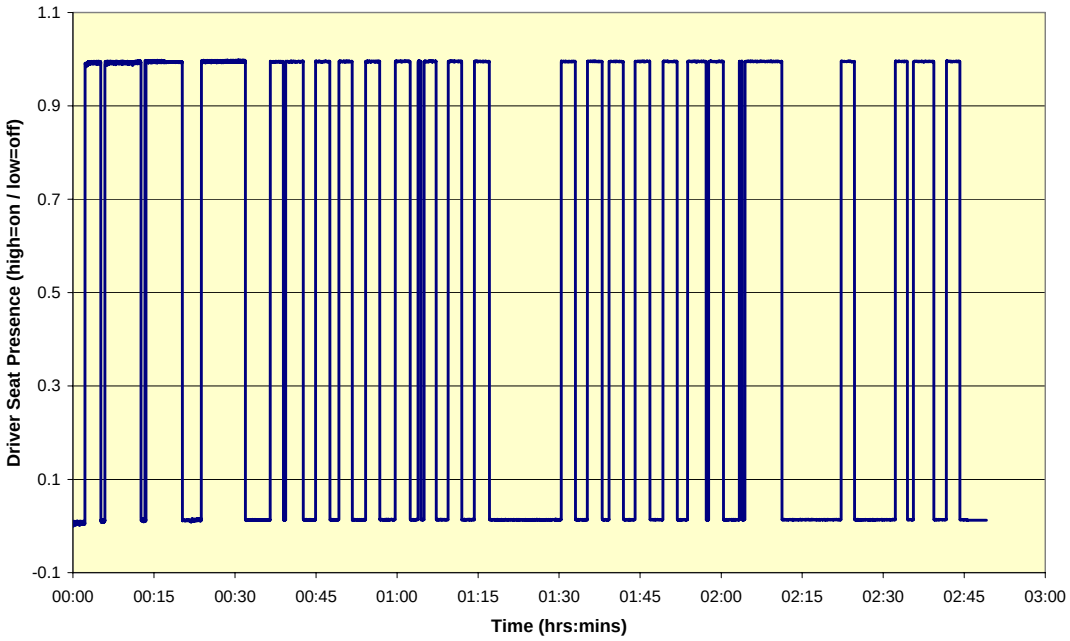

Figure A1.11.5 Linde 2.5 tonne fork lift truck:- driver seat presence time history

Figure A1.11.6 Linde 2.5 tonne fork lift truck:- time histories of weighted 1-minute rms floor accelerations (X, Y and Z-axes)

Figure A1.11.7 Linde 2.5 tonne fork lift truck:- time histories of weighted 1-minute peak seat accelerations (X, Y and Z-axes)

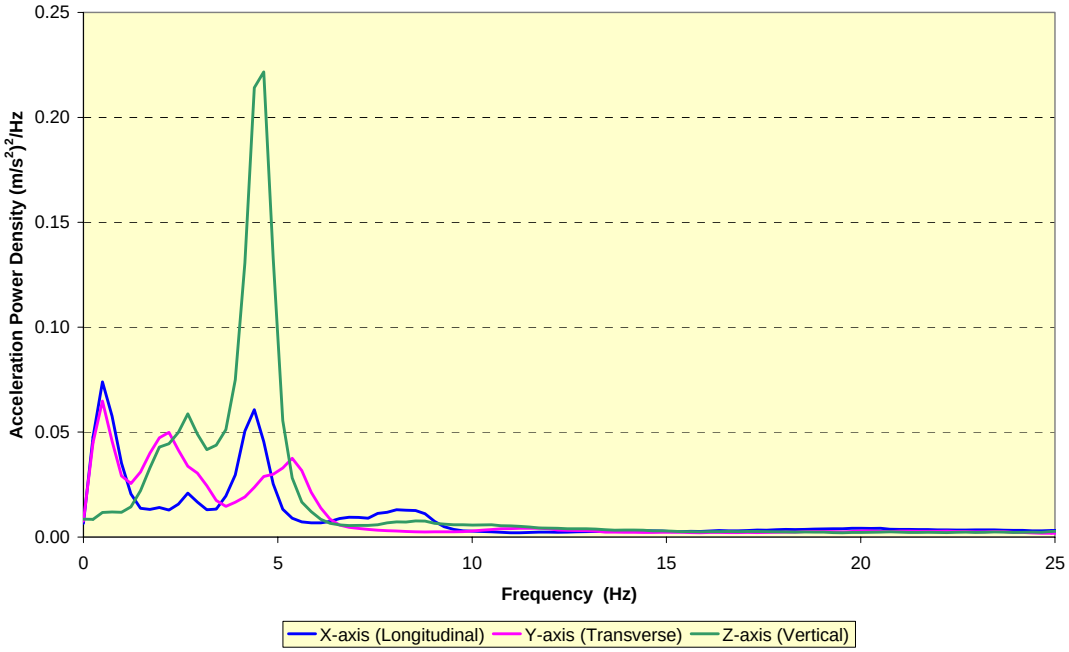

Figure A1.11.8 Linde 2.5 tonne fork lift truck:- acceleration power spectral density (seat)

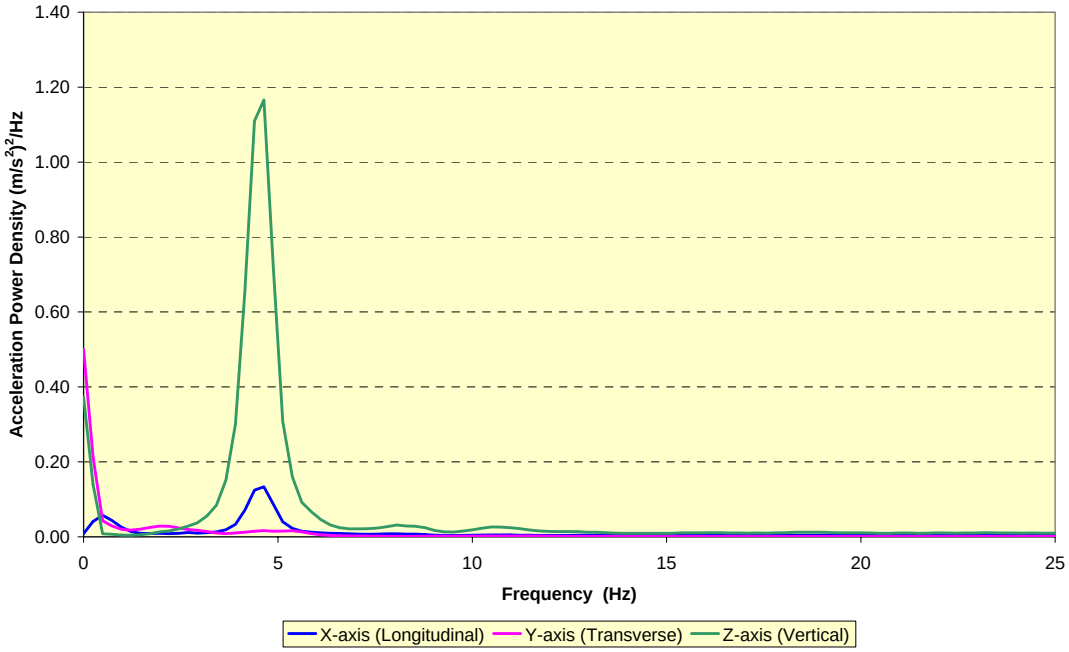

Figure A1.11.9 Linde 2.5 tonne fork lift truck:- acceleration power spectral density (floor)

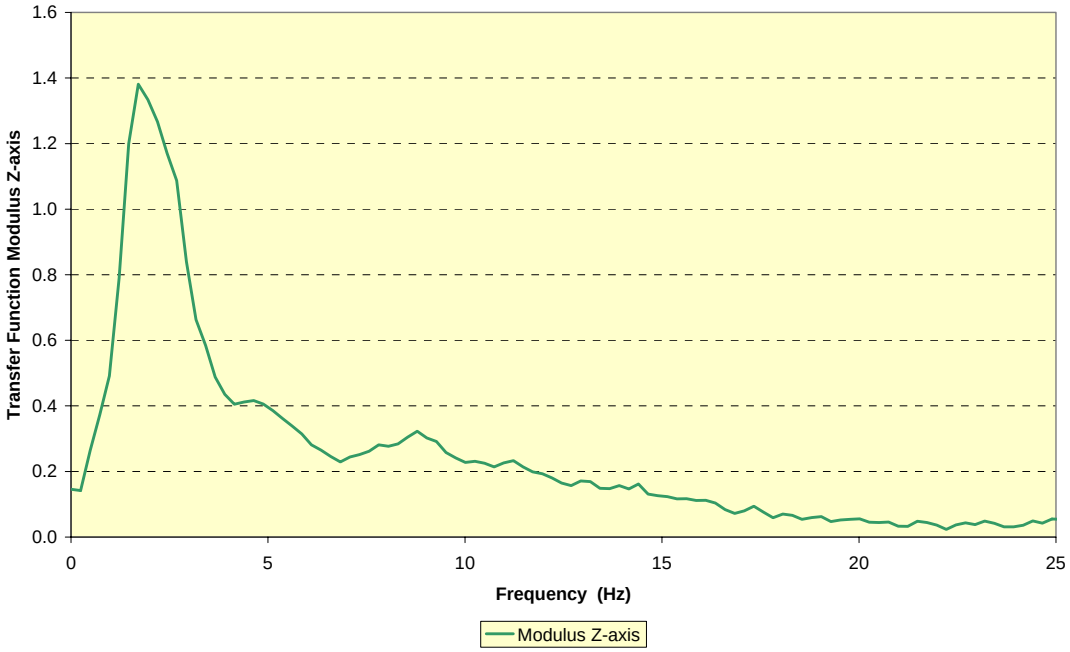

Figure A1.11.10 Linde 2.5 tonne fork lift truck:- seat transfer function – Magnitude

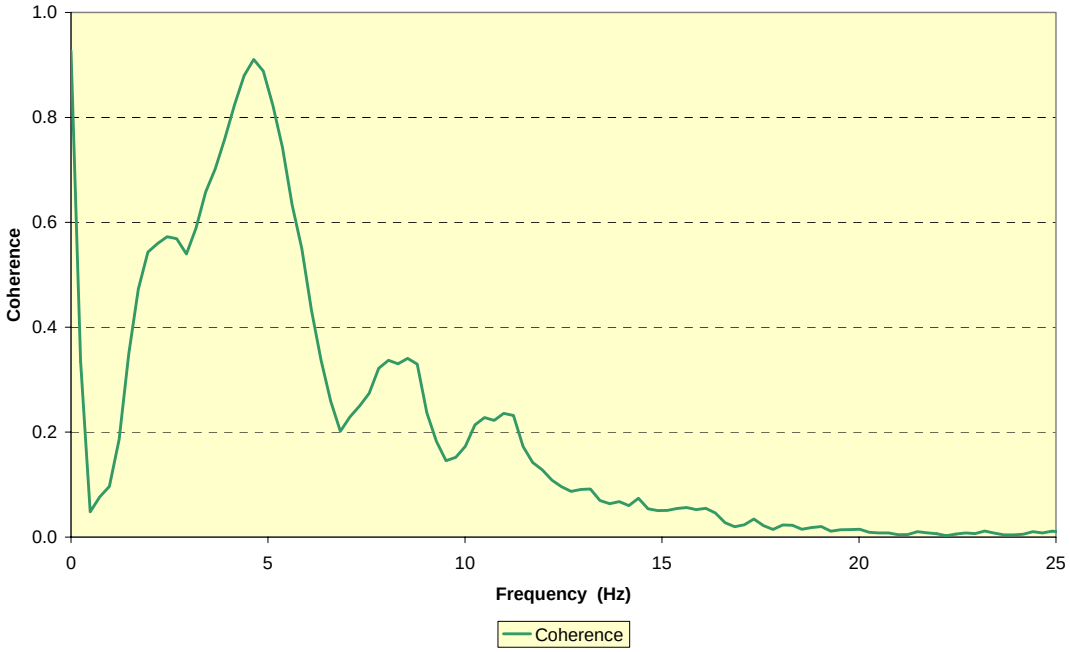

Figure A1.11.11 Linde 2.5 tonne fork lift truck:- seat transfer function – Coherence

Appendix 1.12: Machine No.12 – Caterpillar D70 6.5 tonne Fork Lift Truck

A1.12.1 Operational Details

Date: 7 December 2004

Location: Maltby Colliery, pithead (surface) operations

Operated by: UK Coal, Maltby.

Machine Details:

Make:	Caterpillar
Model:	4SS 70 AVB
Weight:	9550 kg
Capacity:	6600 kg
Power:	69.9 kW
Registration:	
VIN/Serial No:	Fleet No: P 1351
Year of build:	1995
Condition:	Well worn.
Tyre size/make:	Watts Kargo Model K2, 825x15, dualled at front
Tyre pressures:	Solid.
Vehicle Suspension:	None.
Seat Suspension:	Cushion only. The machine tested had a new seat, others had harder cushions.

Operator: Weight: 63.5 kg , Height: 1.75 m.

Instrumentation (transducers):

Seat:-	ICP type PCB 356B40 in seat pad plus operator seat presence switch
Floor: -	ICP type PCB 356B40 attached by magnetic clamp next to seat mounting bolt.

Site Operations:-

At the mine surface, materials other than coal are brought up in tubs or trucks that run on rails. The contents are mainly scrap/surplus and are taken into the reclaims yard for sorting. The trucks, when empty, are carried round to the Stock Yard. In the Stock Yard, trucks are loaded according to "picking orders" required for operations underground. The loaded trucks are placed on rails and assembled into trains for delivery to the pithead. Three fork lift trucks are used for these operations. There is a considerable distance (300 to 500 m) between the Stock Yard and the Reclaims Yard, with a mainly concrete surface that is badly broken (see Figure A1.12.2). The surface in the Stock Yard is smooth concrete. The surface in the Reclaims Yard is particularly rough, and may never have been metalled. At various points between the two yards, and also within the Reclaims Yard, the vehicles have to cross rails in the system that carries the loaded trucks to and from the shaft

Operational Record:-

Recording started: **07:12 hrs** **Duration:-** **3:50 hrs:mins**
Recording stopped: **11:02 hrs**

Time hrs:mins	Duration hrs:mins	Activity : Comments
07:12	**0:00**	Recorders started. Machine drives through Stock Yard and round to Reclaims Yard
07.30	**0:18**	Unloading trucks and distributing around Reclaims Yard. Much of this work is on foot.
07:50	**0:38**	Carries empty truck to Stock Yard and returns for another.
08:02	**0:50**	Travels to Stores to unload a delivery truck
08:09	**0:57**	Travels through Stock Yard to Shaft No 2 and back in to Stock Yard.
08:14	**1:02**	"Order picking" in Stockyard, much of the time off the seat.
09:00	**1:48**	Travels to Reclaims Yard and leaves machine with engine running for 20 minutes.
09:20	**2:08**	Carries two empty trucks round to Stockyard..
09:29	**2:17**	"Order picking", again much time off seat.
09:40	**2:28**	Manoeuvres loaded truck on to rails.
09:46	**2:34**	Places single load on next truck
09:49	**2:37**	Manouevres loaded truck on to rails
09:49	**2:37**	Travels to and from Electrical Shop
10:00	**2:48**	"Order picking" for next truck
10:09	**2:57**	Manoeuvres next truck on to rails, ties down loads and assembles train
10:19	**3:07**	Travels towards Reclaims Yard
10:32	**3:20**	Reaches bottom of Reclaims Yard and starts unloading a returned truck. In this period the driver is off the machine for nearly 10 minutes continuously, but out of sight.
11:02	**3:50**	Arrives at Stores. Engine off. Recorders off.

New seat (as tested)

Older seat

Figure A1.12.1 Seat types (new and old, both unsuspended) fitted to fork lift trucks operating on Maltby Colliery site

Stockyard

Track to Reclaims Yard

Track to Reclaims Yard

Reclaims Yard

Rails (1)

Rails (2)

Figure A1.12.2 Operating conditions on Maltby Colliery site

A1.12.2 Caterpillar D70 6.5 tonne Fork Lift Truck Whole-Body Vibration Data

Larson Davis HVM100	SN:00385	Day	Month	Year
Location:	***Floor***	***7***	***Dec***	***4***
Machine:	Lift Truck: Caterpillar D70			
Reg No:	Fleet No P.1351		Start time:	07:12
Task:	Reclaiming and stocking pit trucks			
Place:	Maltby Colliery			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
03:59	**8.4**	**6.4**	**12.4**	**16.3**
8-hr est tot	*10.0*	*7.6*	*14.7*	*19.3*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.25	***0.22***	***0.56***	***0.65***

Estimated values	**VDV**	**rms/A8**
Time to EAV (hr):	1.2	6.3
Time to ELV (hr):	33.0	33.3

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
9.87	7.63	11.30	12.40

Larson Davis HVM100	SN:00386	Day	Month	Year
Location:	***Seat***	***7***	***Dec***	***4***
Machine:	Lift Truck: Caterpillar D70			
Reg No:	Fleet No P.1351		Start time:	07:12
Task:	Reclaiming and stocking pit trucks			
Place:	Maltby Colliery			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
03:59	**6.3**	**7.1**	**16.9**	**19.4**
8-hr est tot	*7.5*	*8.5*	*20.1*	*23.1*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.30	***0.30***	***1.06***	***1.14***

Estimated values	**VDV**	**rms/A8**
Time to EAV (hr):	0.3	1.8
Time to ELV (hr):	9.5	9.4

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
4.59	5.12	15.90	15.90

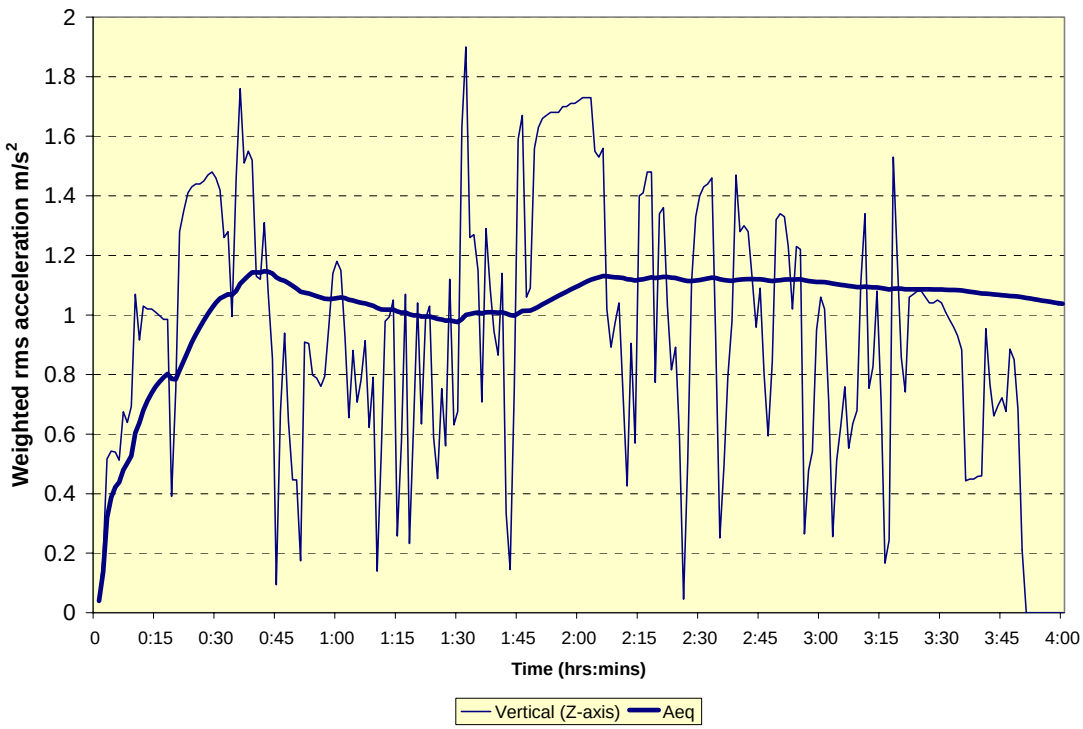

Figure A1.12.3 CAT D70 6.5 tonne fork lift truck:- time history of weighted 1-minute rms seat accelerations (Z-axis) and equivalent continuous rms acceleration (Aeq)

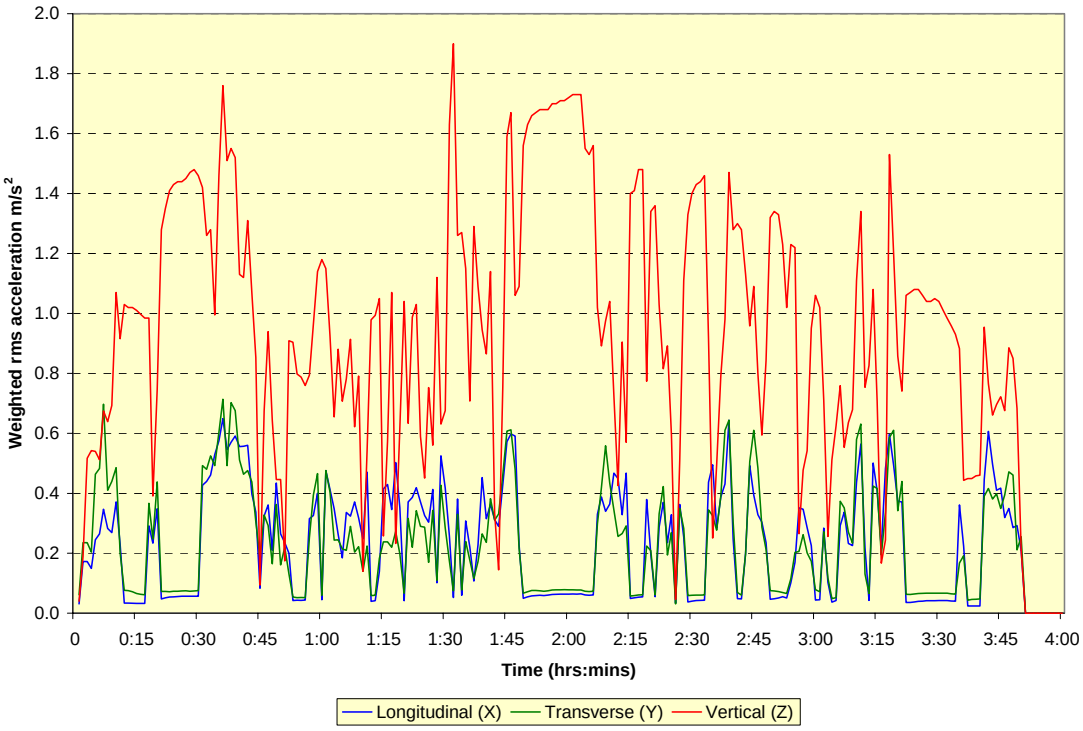

Figure A1.12.4 CAT D70 6.5 tonne fork lift truck:- time histories of weighted 1-minute rms seat accelerations (X, Y and Z-axes)

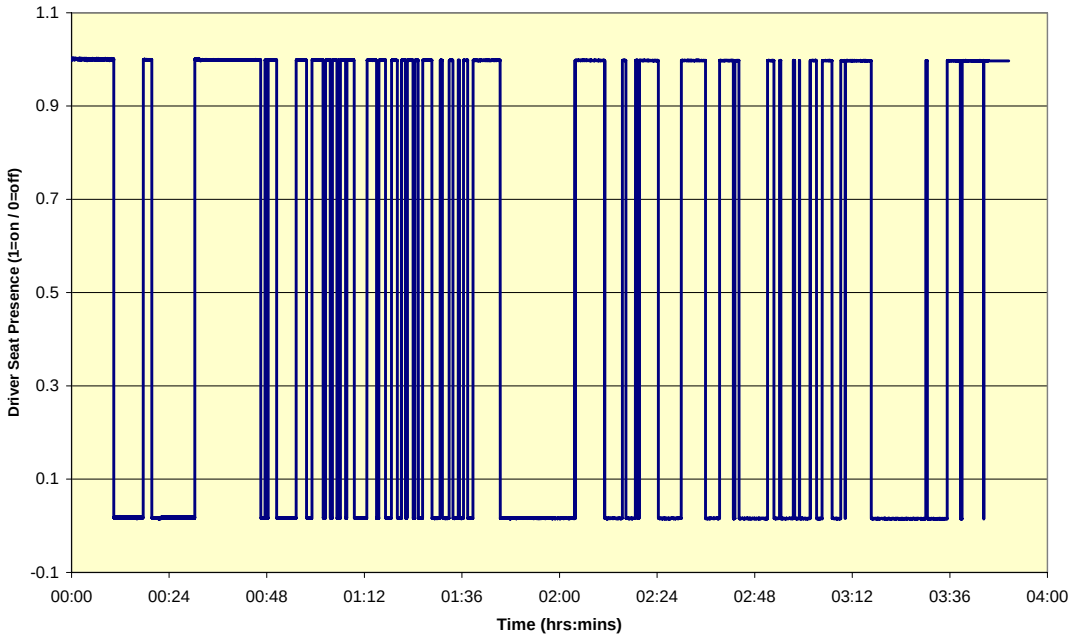

Figure A1.12.5 CAT D70 6.5 tonne fork lift truck:- driver seat presence time history

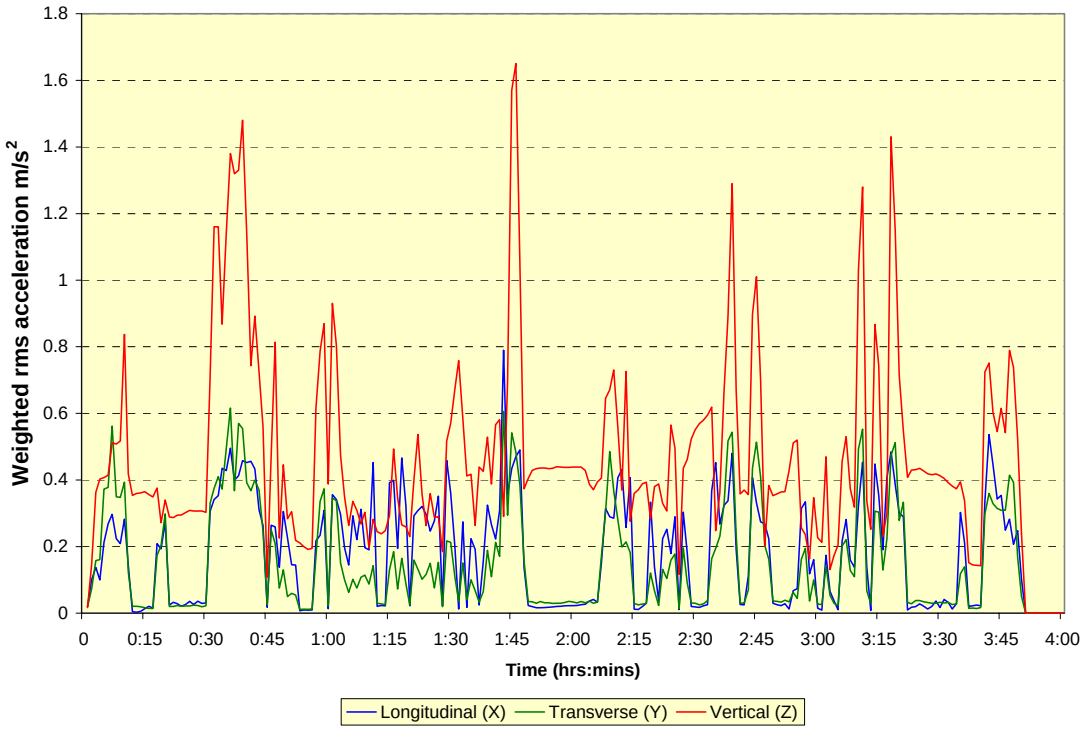

Figure A1.12.6 CAT D70 6.5 tonne fork lift truck:- time histories of weighted 1-minute rms floor accelerations (X, Y and Z-axes)

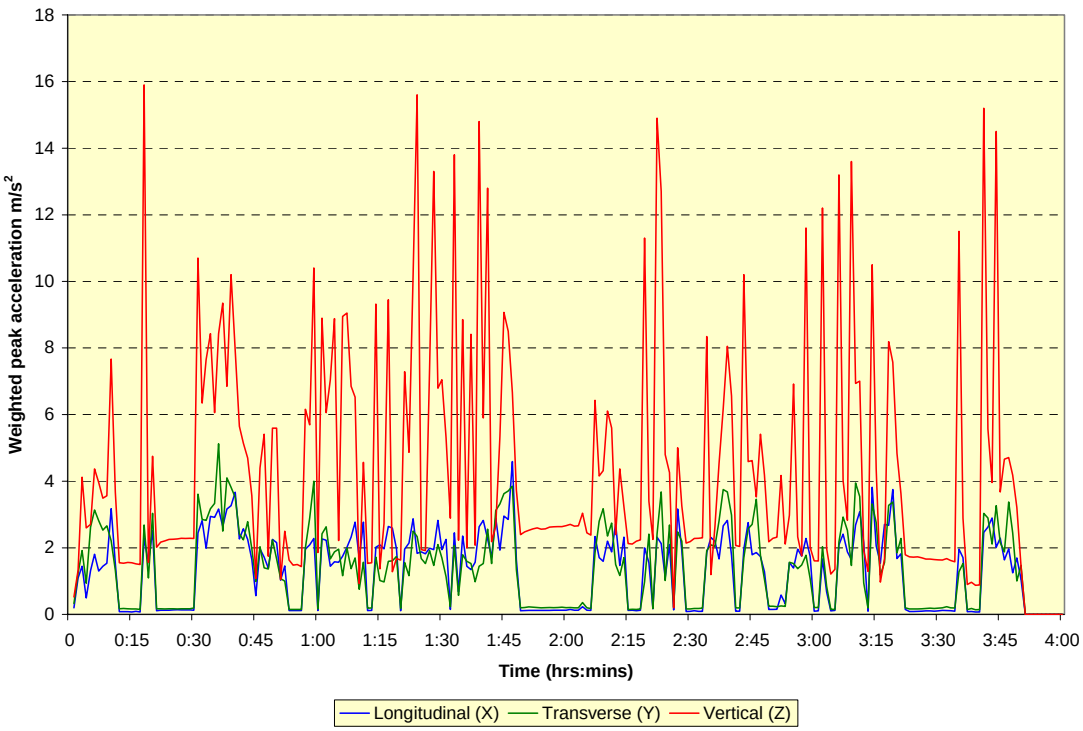

Figure A1.12.7 CAT D70 6.5 tonne fork lift truck:- time histories of weighted 1-minute peak seat accelerations (X, Y and Z-axes)

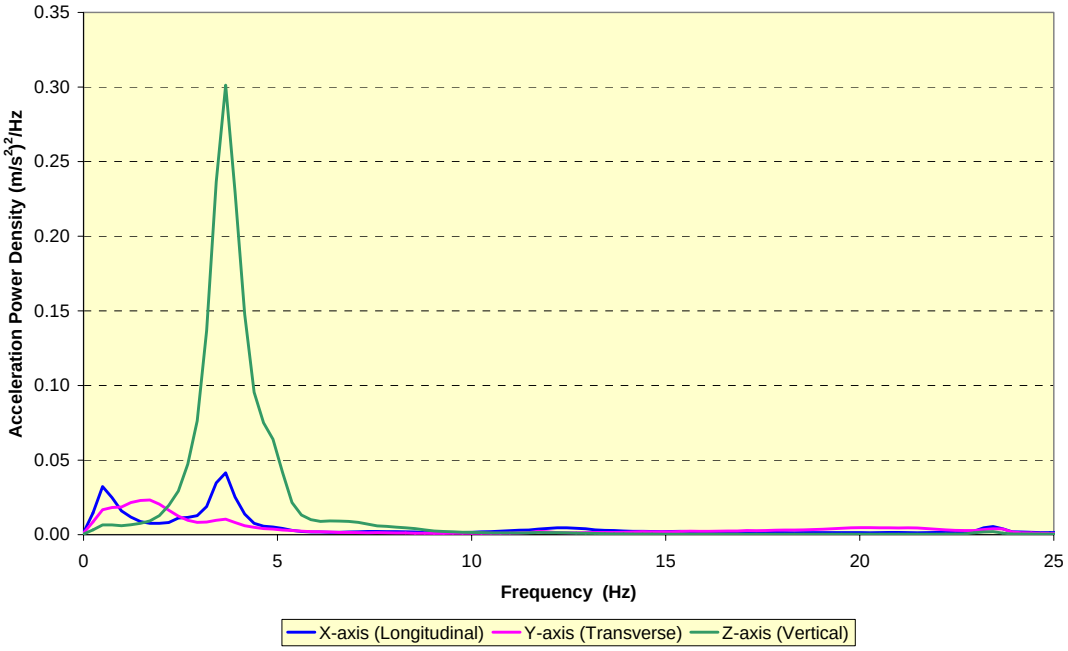

Figure A1.12.8 CAT D70 6.5 tonne fork lift truck:- acceleration power spectral density (seat) – for sections of recording period when driver is 'on-seat'

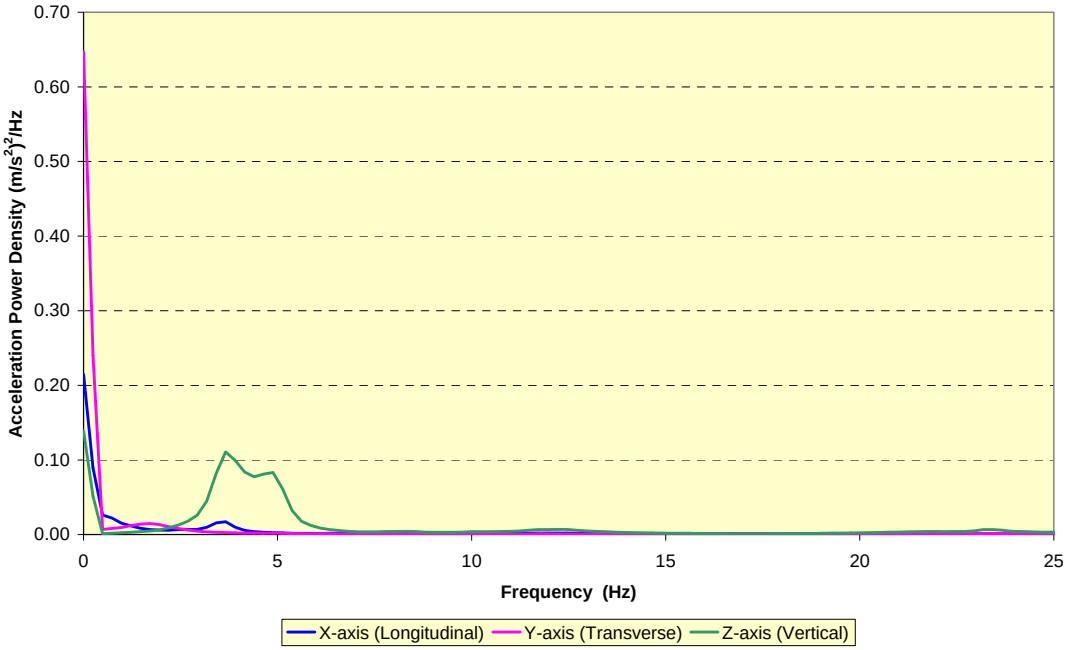

Figure A1.12.9 CAT D70 6.5 tonne fork lift truck:- acceleration power spectral density (floor) – for sections of recording period when driver is 'on-seat'

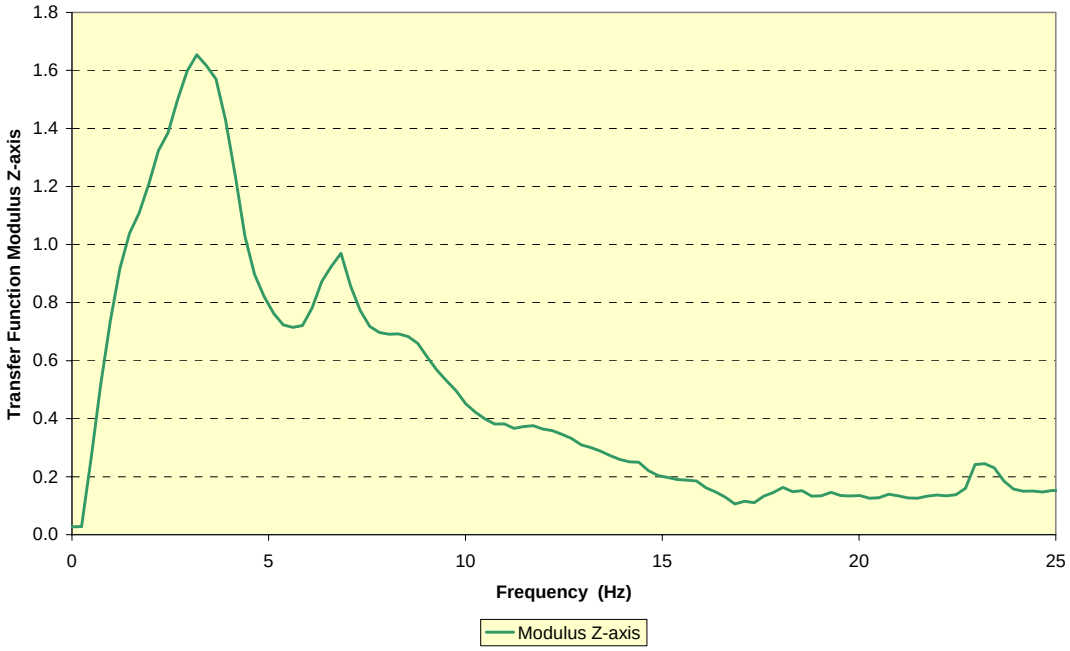

Figure A1.12.10 CAT D70 6.5 tonne fork lift truck:- seat transfer function – Magnitude – for sections of recording period when driver is 'on-seat'

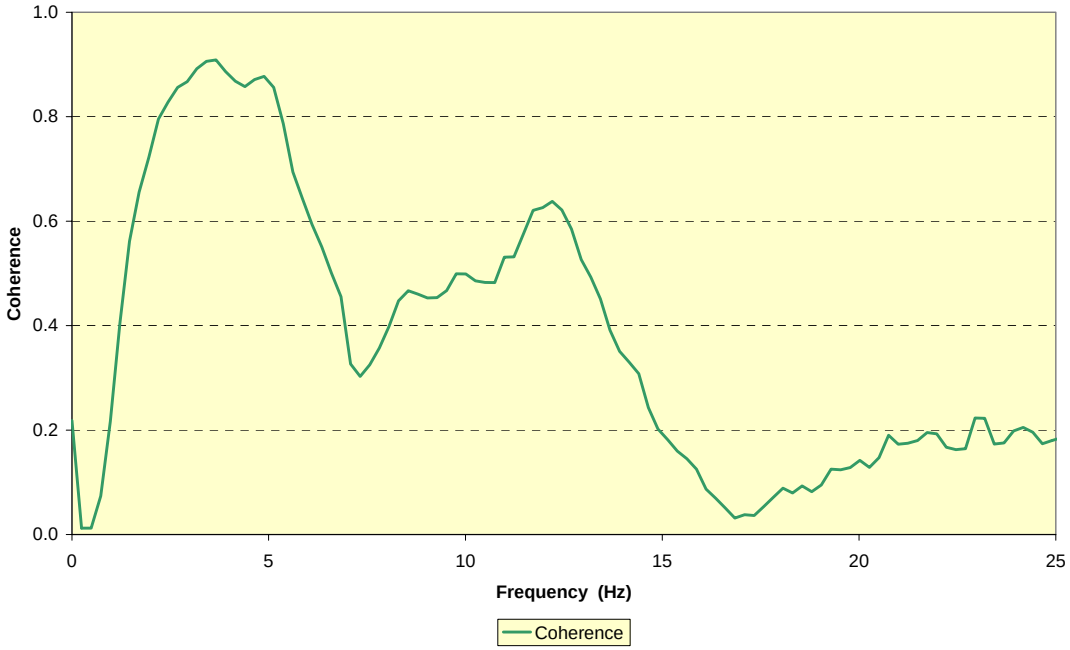

Figure A1.12.11 CAT D70 6.5 tonne fork lift truck:- seat transfer function – Coherence – for sections of recording period when driver is 'on-seat'

Appendix 1.13: Machine No.13 – Volvo EC15B Compact 360° Excavator

A1.13.1 Operational Details

Date: Friday 11th February 2005

Location: J. H. Excavation
52 Pilgrims Close,
Harlington,
Beds

Machine Make: Volvo 1.5 tonne, rubber-tracked 360° excavator
Model No: EC15B XTV
P.I.N. 272 41400
Operating mass: 1636 kg
Age: 2003
Engine power: 11.1 kW
Operating hours: 634 hrs
Machine condition: very good / as new

Track system: Bridgestone rubber-type
Track spacing: 1.09 m
Track width: 0.23 m
Track length (in ground contact): ≈ 1.2 m

Operator's name: Jeremy Harris (owner)
Skill/technique: Experienced / steady / smooth
Weight: 128 kg

Tyre pressure: N/A

Vehicle Suspension: None

Driver's seat:-
Make: Grammer
Model: MSG20
Type: Compact height / limited travel, mechanical semi-Z-axis suspension (suspension of backrest, rear of seat pan; front of seat pan fixed pivot.)
Condition: In good working order. Correctly adjusted for operator's weight.

Operators Cab/ROPS: ISO-mounted from digger chassis, but operator's seat fixed directly to chassis.

WBV Instrumentation:
Seat:- B&K seat pad plus operator seat presence switch
Floor:- ICP-type PCB 356B40 tri-axial accelerometer (from SRI PCB seat pad) attached to cab floor directly under seat via magnetic mounting
Both pieces of instrumentation feeding through Larson Davis Human Vibration Meters (LD 215 – Floor) & (LD 272 – Seat) and recording directly to Teac DR-C2 PC-card recorder.

Site Operation:- Machine being used to excavate house extension footings / patio area to rear of semi-detached residential property. Loading excavated material into a compact site dumper for removal. No significant ground-induced vibrations – Moderate / smooth (but typical) operating conditions.

Ground conditions:- Moist, sticky clay.

Operational Comments:-

- Operating conditions initially moist clay subsoil and clay based topsoil, subsequently moving dug material and loading it into a skip loader-type compact site dumper;
- No significant vibrations were generated through the machine whilst excavating material, but machine vibration produced by dumping of material either onto spoil pile or alternatively into soil transporting machine.
- Moderate / smooth operating conditions, but typical of a machine of this size undertaking domestic construction / landscaping operations.

Operational Record:-

Recording started: **14:08 hrs** **Duration:-** **3:01 hrs**
Recording stopped: **17:09 hrs**
Data Analysis Period:- **0:36 – 3:01 hrs** **Analysis Duration:-** **2:26hrs**

Time (hrs:mins)	Duration (hrs:mins)	Activity : Comments
14.08	**0:00**	Recording begins
14.09	**0:01**	Digging / excavation begins
14.12	**0:04**	Digging momentarily stopped while operator makes phone call
14.13	**0:05**	Digging recommences
14.21	**0:13**	Operations stop momentarily to check instrumentation, reasonable values appearing on both Larson Davies meters. Operation proceeding well
14.22	**0:14**	Excavation restarted
14.27	**0:19**	Operation stopped momentarily while operator takes phone call
14.28	**0:20**	Operation restarted
14.33	**0:25**	Operation stopped for tea
14.42	**0:34**	Operation recommences after tea break
15.04	**0:56**	Operations stopped momentarily while operator takes a phone call
15.04	**0:56**	Operation restarted
15.23	**1:15**	Machine being used to fill skip loader / soil transporting machine. Excavator operator has been in seat throughout entire operating period with the exception of tea break.
15.38	**1:30**	Machine excavating footings at rear of patio area.
15.45	**1:37**	Operator leaves seat
15.45	**1:37**	Operator re-enters cab
15.46	**1:38**	**Comment:** Operator digging footings for retaining wall, machine now being subject to slightly more vibration than previously.
17.08	**3:00**	Operation stopped
17.09	**3:01**	Recorders turned off.

Figure A1.13.1 Volvo EC15B 1.5 tonne compact 360° excavator excavating footings for house extension and patio

A1.13.2 Volvo EC15B Compact 360° Excavator Whole-Body Vibration Data

Larson Davis HVM100	SN:00215	Day	Month	Year
Location:	***Floor***	***11***	***2***	***5***
Machine:	Volvo 1.5 tonne compact excavator			
Model No:	EC15B XTV		Start time:	14:44
Task:	Excavating house extension footings			
Place:	Harlington, BEDS			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
02:26	**7.3**	**5.4**	**5.5**	**10.4**
8-hr est tot	*9.9*	*7.2*	*7.4*	*14.1*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.37	***0.25***	***0.24***	***0.51***

Estimated values	**VDV**	**rms/A(8)**
Time to EAV (hr):	5.8	14.4
Time to ELV (hr):	165.1	76.1

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
5.40	4.84	9.05	10.30

Larson Davis HVM100	SN:00272	Day	Month	Year
Location:	***Seat***	***11***	***2***	***5***
Machine:	Volvo 1.5 tonne compact excavator			
Model No:	EC15B XTV		Start time:	14:44
Task:	Excavating house extension footings			
Place:	Harlington, BEDS			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
02:26	**8.4**	**6.1**	**8.7**	**13.0**
8-hr est tot	*11.3*	*8.2*	*11.7*	*17.6*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.42	***0.30***	***0.22***	***0.56***

Estimated values	**VDV**	**rms/A(8)**
Time to EAV (hr):	2.9	11.4
Time to ELV (hr):	82.3	60.3

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
6.54	4.82	24.50	24.50

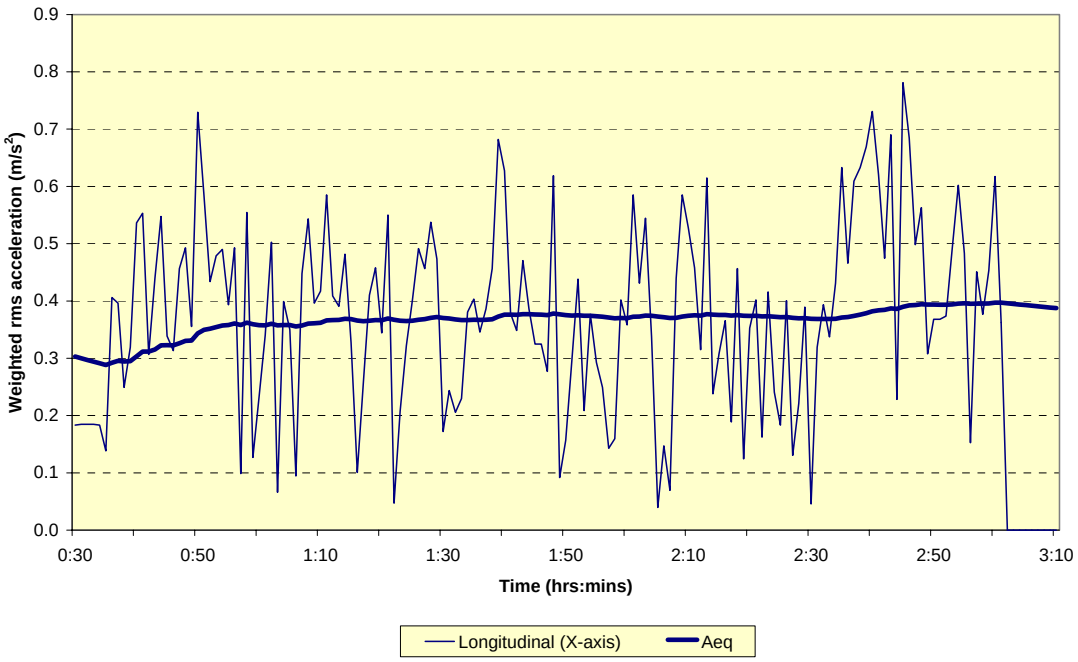

Figure A1.13.2 Volvo EC15B compact 360° excavator:- time history of weighted 1-minute rms seat accelerations (X-axis) and equivalent continuous rms acceleration (Aeq)

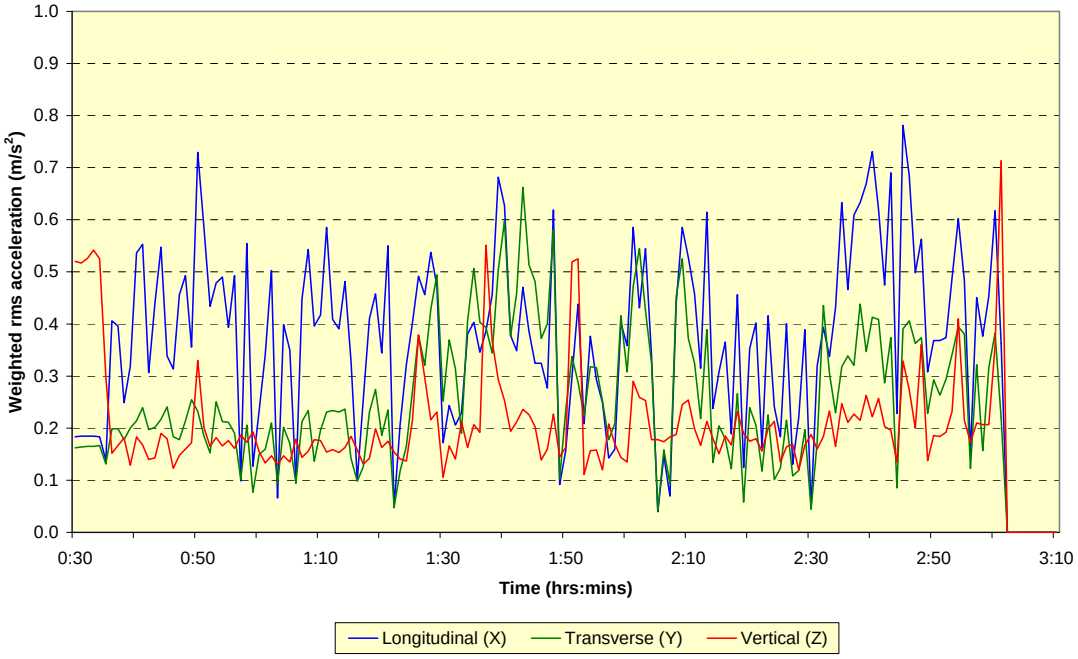

Figure A1.13.3 Volvo EC15B compact 360° excavator:- time histories of weighted 1-minute rms seat accelerations (X, Y and Z-axes)

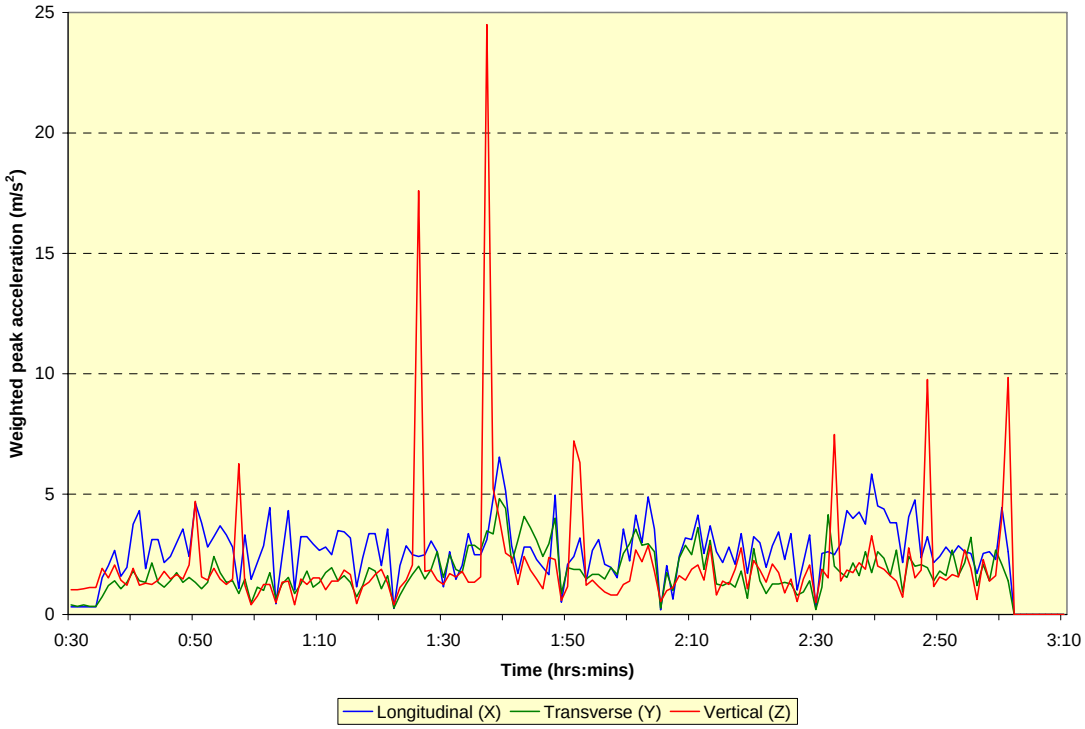

Figure A1.13.4 Volvo EC15B compact 360° excavator:- time histories of weighted 1-minute peak seat accelerations (X, Y and Z-axes)

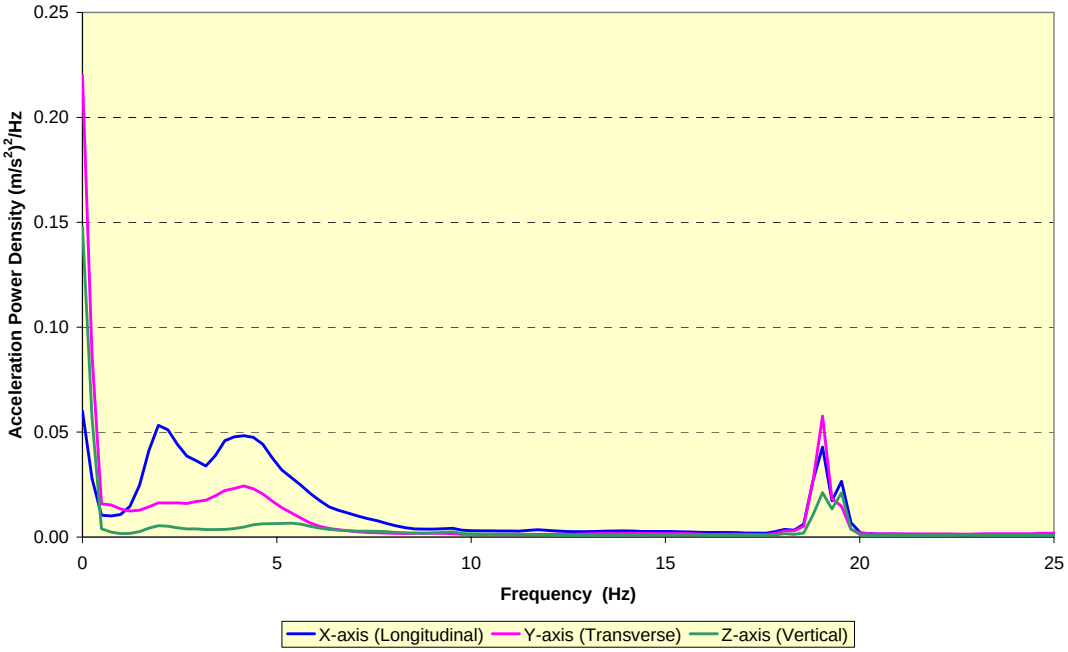

Figure A1.13.5 Volvo EC15B compact 360° excavator:- acceleration power spectral density (seat)

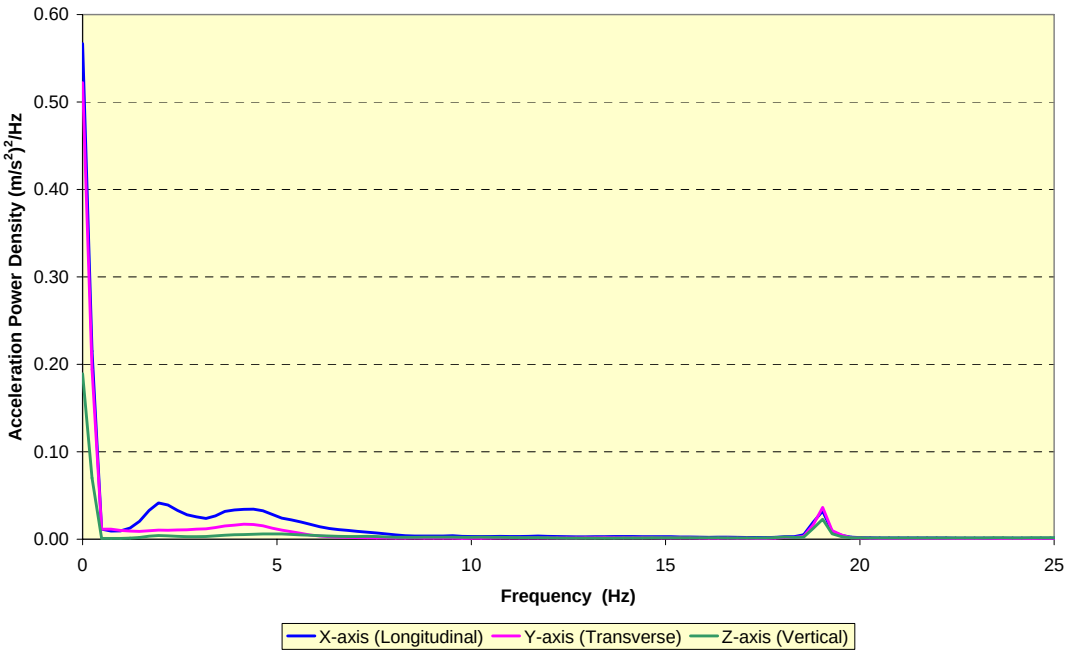

Figure A1.13.6 Volvo EC15B compact 360° excavator:- acceleration power spectral density (floor)

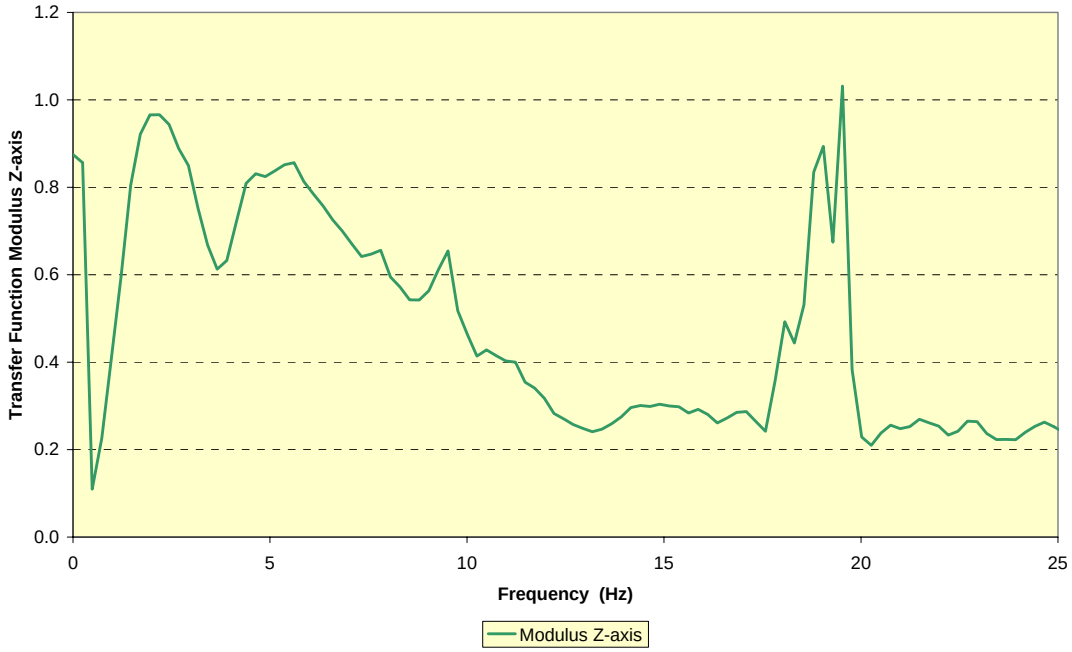

Figure A1.13.7 Volvo EC15B compact 360° excavator:- seat transfer function – Magnitude

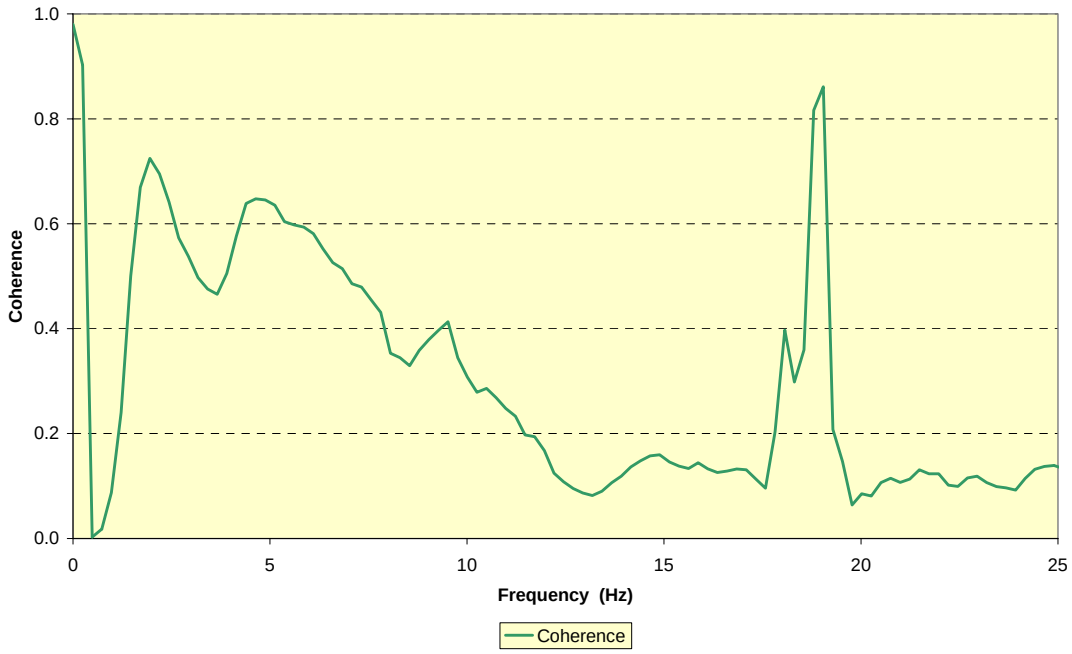

Figure A1.13.8 Volvo EC15B compact 360° excavator:- seat transfer function – Coherence

Appendix 1.14: Machine No.15 – Caterpillar 777B 80-tonne Rigid Dump Truck

A1.14.1 Operational Details

Date:	17th February 2005
Location:	UK Coal, Hicks Lodge
Machine Details:	
Make:	Caterpillar
Model:	777B
Weight:	86.6 Tonnes (Unladen)
Capacity:	80 Tonnes
Power:	798 HP (595 kW)
Registration:	Fleet No. P1023
VIN/Serial No:	4YC1125
Year of build:	1990
Condition:	Well worn, but well maintained.
Tyre size/make:	Bridgestone steel radial 2700R49, single at front, dual at rear.
Tyre pressures:	100 lb/in^2 (7 Bar)
Vehicle Suspension:	Front wheels suspended through hydraulic cylinders.
Seat Suspension:	KAB 515 or 525 mechanical suspension. Condition appeared good, but height/weight setting hard on upper stop.

Operated by: UK Coal Mining Ltd, Hicks Lodge.

Operator: Weight 100 kg , Height 1.88 m.

WBV Instrumentation (transducers):

Seat:-	ICP type PCB 356B40 in seat pad plus operator seat presence switch
Floor: -	ICP type PCB 356B40 attached by magnetic clamp next to seat mounting rail.

Site Operations:-

The open cast site at Hicks Lodge was worked out at the time of the measurements. The only operations were Restoration, which involved carrying previously stored overburden from the excavator to the areas then being filled. During the measurement period, tow areas were being filled. The first was 50 to 100m from the excavator, the second 100 to 200 m distant. The haul route was along or across an old haul road, and was levelled by a Grader.

Before and after the work period, the machine travelled from and to the fitting shop, traversing about 400m of mainly well-graded road, but including one or two more severe bumps.

The start of work was delayed for 40 minutes because rain had made the surface unsuitable for restoration work.

Because of the number of trucks and the short haul routes, there was considerable waiting time before each load was taken from the excavator.

NB. The surface was better maintained than during mining operations for a number of reasons:

There were fewer trucks using it, but the same grading effort was available.

The haul route was shorter, and did not cross different levels, which would have had different rates of sinkage.

The haul route was on more or less level ground.

Operational Record:-

Recording started: **11:19 hrs** **Duration:-** **3:44 hrs:mins**
Recording stopped: **15:03 hrs**

Time (hrs:mins)	Duration (hrs:mins)	Activity : Comments
11:19	**0:00**	Recorders started. Machine drives from Fitting Shop to work site. There followed a continuous sequence of waiting, loading, hauling, dumping and returning to wait. There were about 25 cycles, each of 7 to 9 minutes.
15:03	**3:44**	Return to Fitting Shop. Recorders switched off.

Operational and Data Analysis Comments:-

- The rms vibration for the largest single axis (Vertical) was 0.37 ms^{-2}. If the haul route had been long enough to eliminate the waiting time (40% to 45%), this would have been about 0.5 ms^{-2}, and a rougher haul road would probably have increased the level still further;
- The working week comprises five and a half 12-hour shifts. This would increase the A(8) values to about 0.47 ms^{-2} (0. 63 ms^{-2}.without the waiting time);
- The vibration magnitudes are best controlled by appropriate grading of the haul roads. The difficulty of achieving adequate grading in working mines may be a problem.;
- Like-for-like comparisons of different dumpers (rigid and articulated) is required to determine the most suitable.

Figure A1.14.1 Site Operation

A1.14.2 CAT 777B 80-tonne Rigid Dump Truck Whole-Body Vibration Data

Larson Davis HVM100	SN:00385	Day	Month	Year
Location:	***Floor***	***17***	***Feb***	***5***
Machine:	CAT 777B Dump Truck			
Reg No:	P 1023		Start time:	11:19
Task:	Load-Haul-Dump			
Place:	Hicks Lodge Mine (Restoration)			

Total VDV (m/s$^{1.75}$)

Time	X	Y	Z	Sum
03:44	**7.9**	**5.5**	**11.0**	**14.4**
8-hr est tot	*9.5*	*6.7*	*13.3*	*17.4*

Average r.m.s. (Aeq) (m/s^2)

X	Y	Z	Sum
0.32	***0.26***	***0.36***	***0.55***

Estimated values	**VDV**	**rms/A8**
Time to EAV (hr):	1.8	15.0
Time to ELV (hr):	49.8	79.6

Maximum peak value (m/s^2)

X	Y	Z	Sum
8.76	3.98	16.90	16.80

Larson Davis HVM100	SN:00386	Day	Month	Year
Location:	***Seat***	***17***	***Feb***	***5***
Machine:	CAT 777B Dump Truck			
Reg No:	P 1023		Start time:	11:19
Task:	Load-Haul-Dump			
Place:	Hicks Lodge Mine (Restoration)			

Total VDV (m/s$^{1.75}$)

Time	X	Y	Z	Sum
03:44	**7.7**	**8.3**	**12.2**	**15.9**
8-hr est tot	*9.3*	*10.0*	*14.8*	*19.3*

Average r.m.s. (Aeq) (m/s^2)

X	Y	Z	Sum
0.34	***0.35***	***0.37***	***0.61***

Estimated values	**VDV**	**rms/A8**
Time to EAV (hr):	1.1	14.9
Time to ELV (hr):	32.5	78.7

Maximum peak value (m/s^2)

X	Y	Z	Sum
7.92	4.93	32.60	32.40

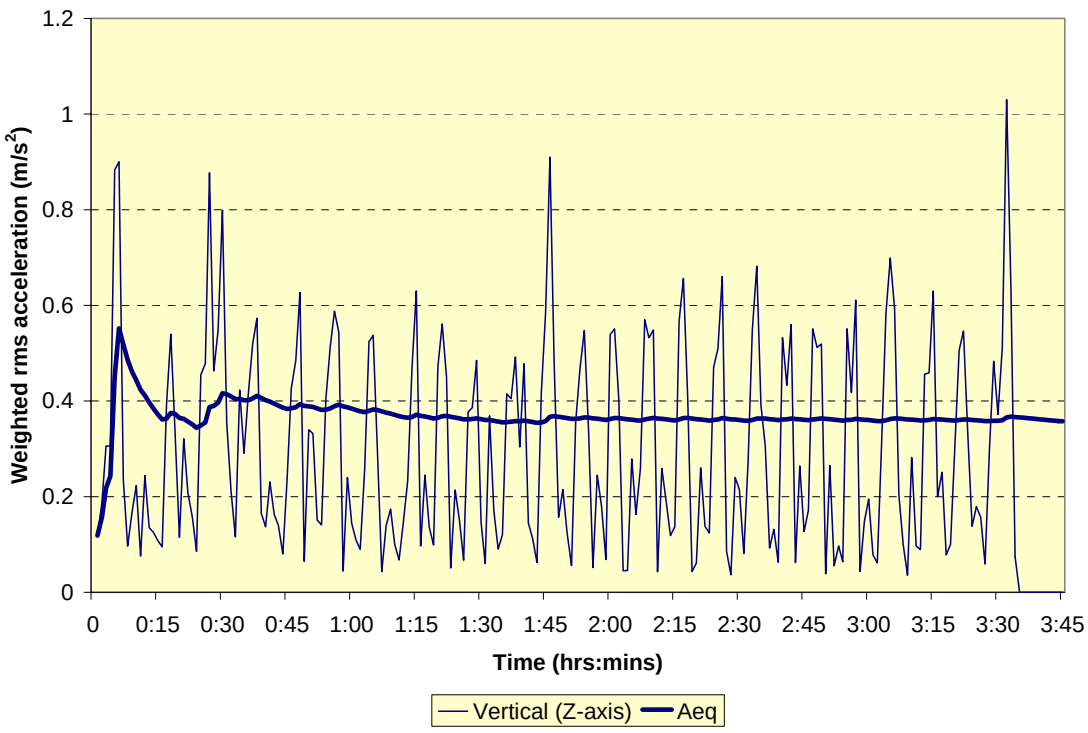

Figure A1.14.2 CAT Rigid Dump Truck:- time history of weighted 1-minute rms seat accelerations (Z-axis) and equivalent continuous rms acceleration (Aeq)

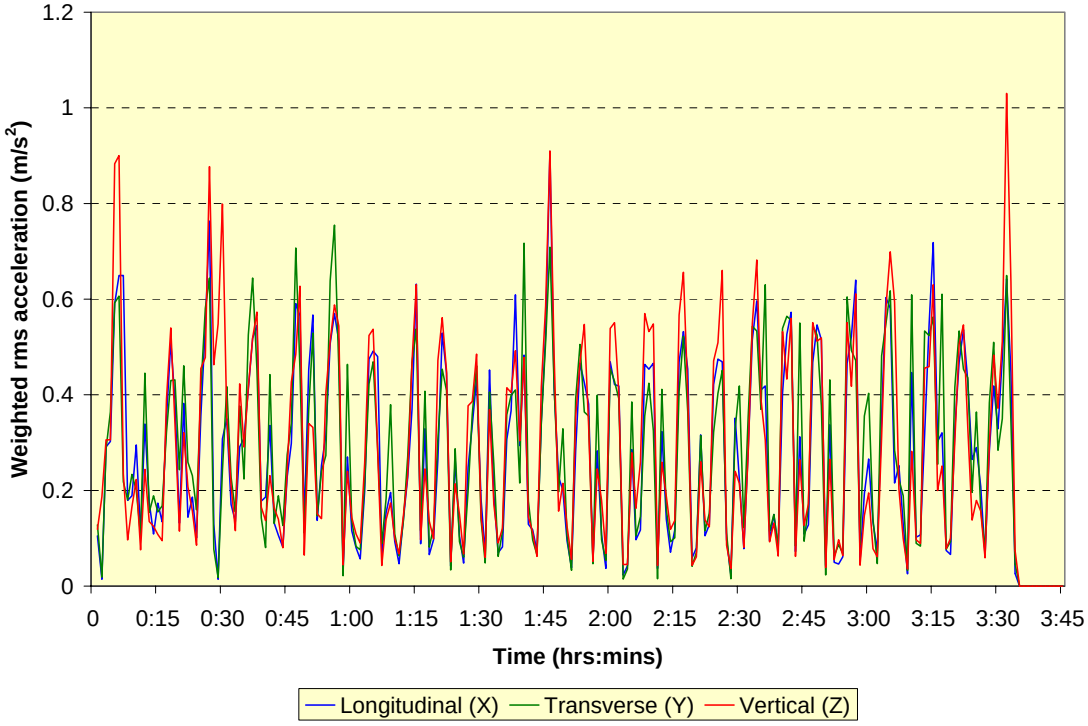

Figure A1.14.3 CAT Rigid Dump Truck:- time histories of weighted 1-minute rms seat accelerations (X, Y and Z-axes)

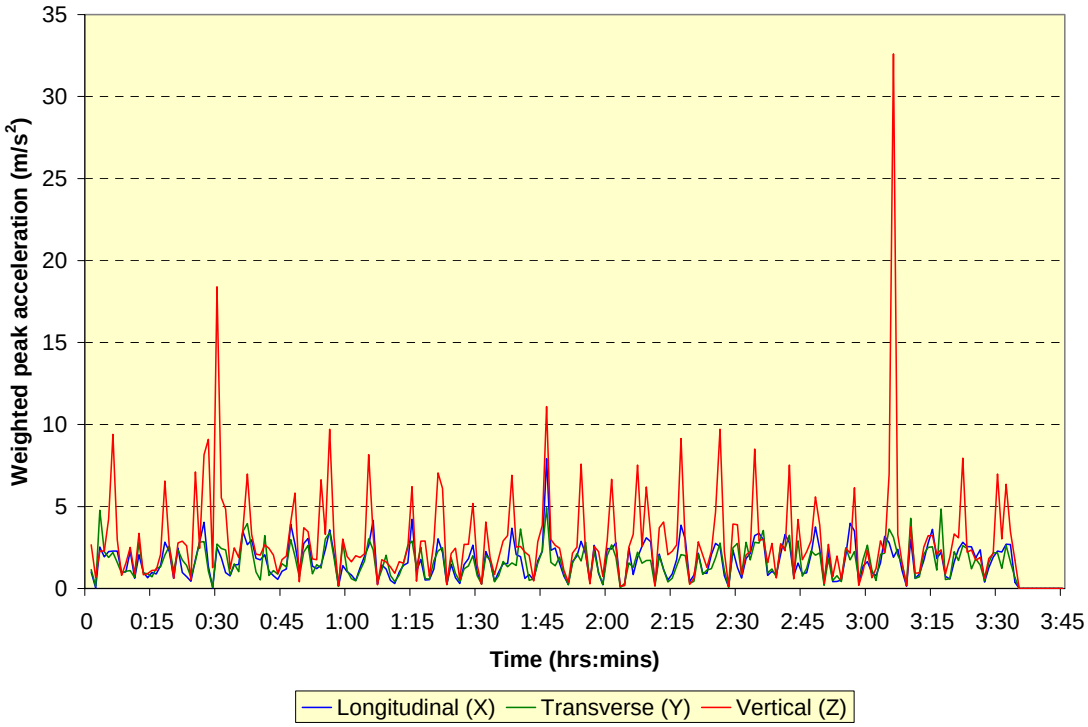

Figure A1.14.4 CAT Rigid Dump Truck:- time histories of weighted 1-minute peak seat accelerations (X, Y and Z-axes)

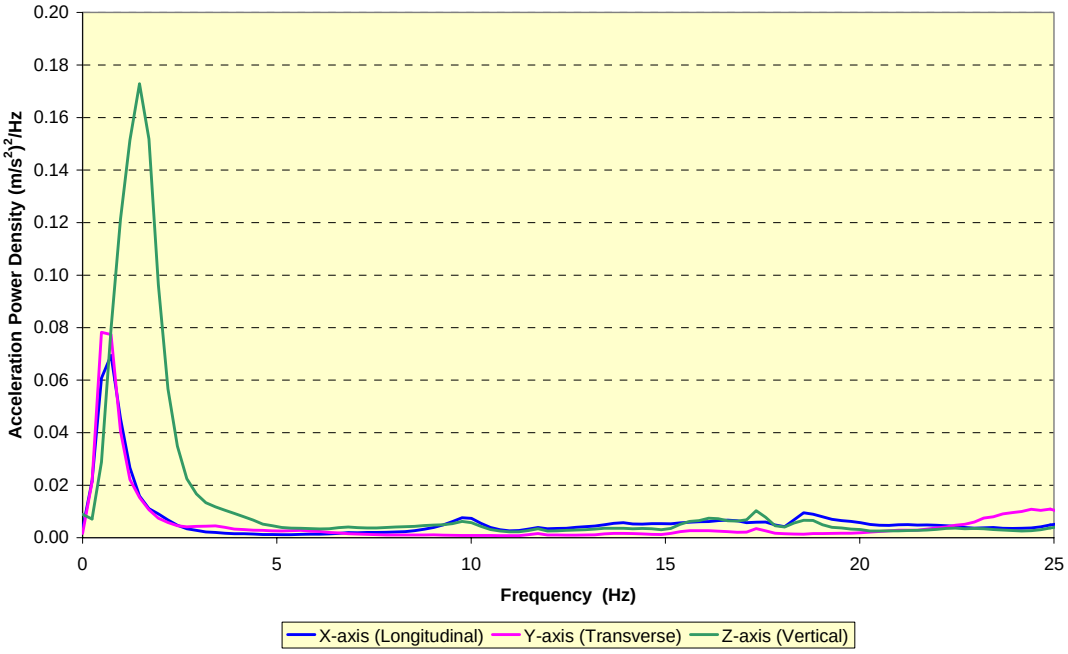

Figure A1.14.5 CAT Rigid Dump Truck:- acceleration power spectral density (seat)

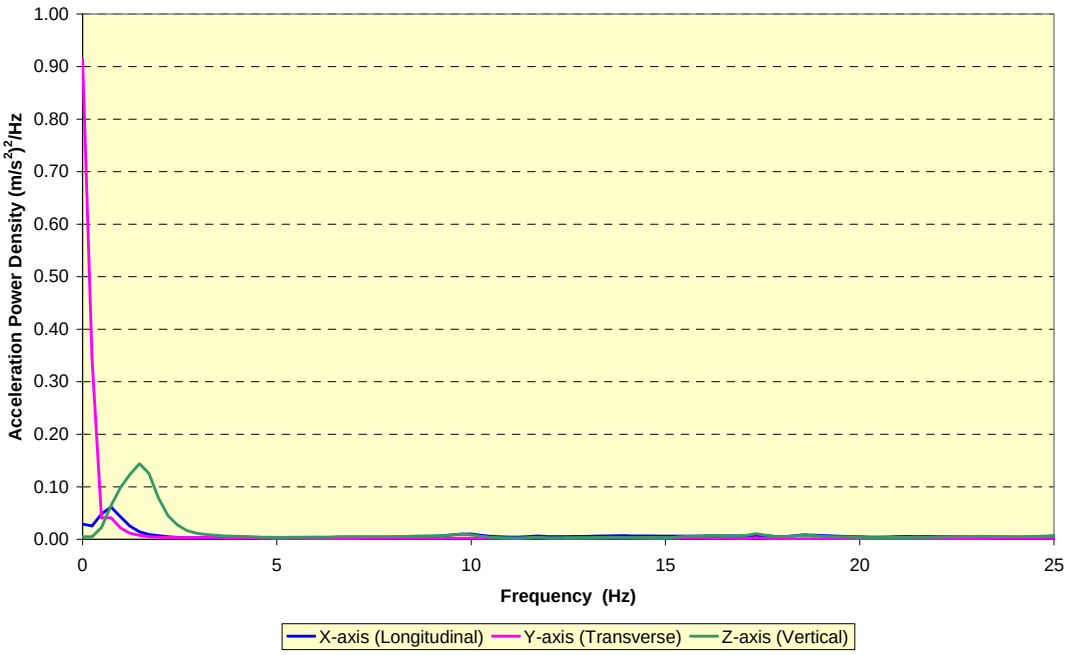

Figure A1.14.6 CAT Rigid Dump Truck:- acceleration power spectral density (floor)

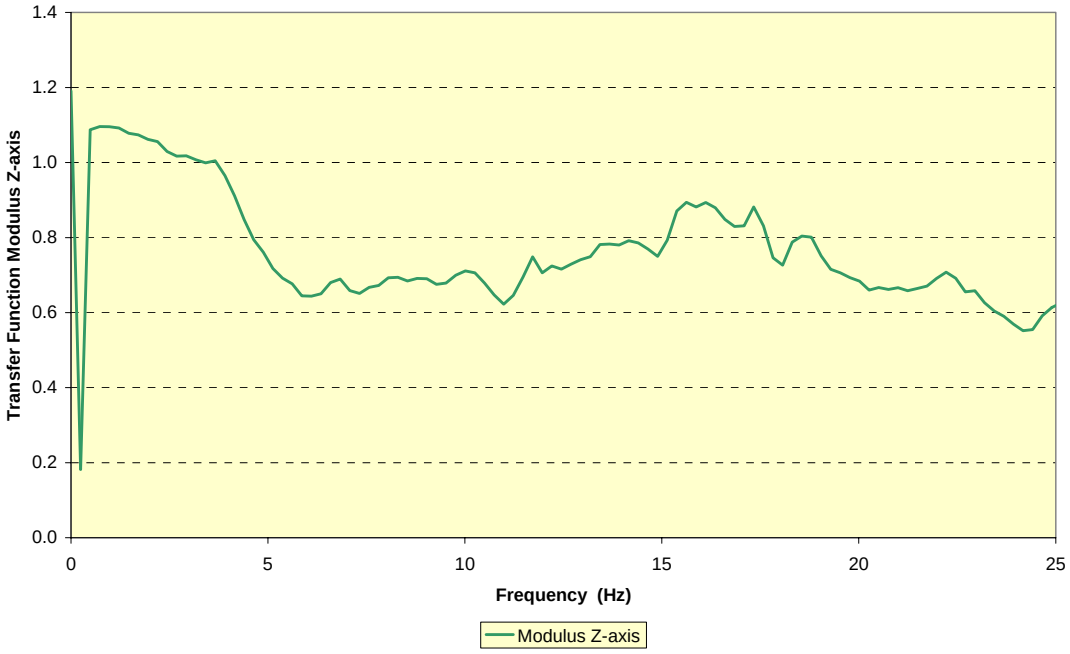

Figure A1.14.7 CAT Rigid Dump Truck:- seat transfer function – Magnitude

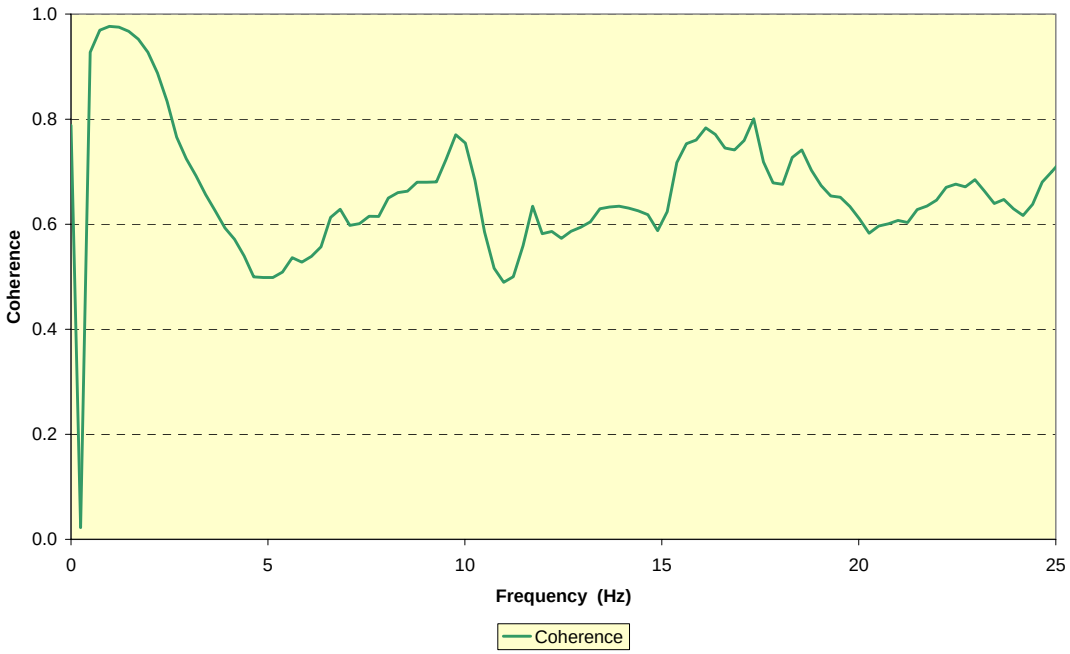

Figure A1.14.8 CAT Rigid Dump Truck:- seat transfer function – Coherence

Appendix 1.15: Machine No.15 – Caterpillar 236 Skidsteer Loader

A1.15.1 Operational Details

Date: 22nd March 2005

Location: Thicknall House, Hagley

Owned by: Hewden Hire, Redditch
Operated by: David Paul Construction.

Machine Details:
- **Make:** Caterpillar
- **Model:** 236
- **Weight:** 3,288 kg (Unladen)
- **Capacity:**
- **Power:** 44 kW
- **Registration:** Fleet No.122772
- **VIN/Serial No:** 4Y204388
- **Year of build:** 2001
- **Condition:** Good.
- **Tyre size/make:** Michelin Stabil'X 12R16.5X2SL. Tread scrubbed off.
- **Tyre pressures:** 30 lb/in^2 (2 Bar)

Vehicle Suspension: None.

Seat Suspension: Compact mechanical Z-axis suspension: badged Caterpillar, possibly Grammer. Condition appeared good. Height/weight setting within working range.

Operator: Weight 100 kg Height 1.85 m.

WBV Instrumentation (transducers):
Seat:- ICP type PCB 356B40 in seat pad plus operator seat presence switch
Floor: ICP type PCB 356B40 attached by magnetic clamp next to seat mounting rail.

Site Operations:-

Use of this type of machine on small building sites is typically very intermittent.

During the project at Thicknall House, the Loader was used mostly for moving materials around the site, on many days actually operating for only a few minutes at a time, and on some days not moving at all. On the day before the measurements, it had been used for levelling a new gravel drive, and had operated more or less continuously for 4 hours.

On the day of the measurements (last day of hire), the machine was used in the course of preparing a drive entrance for tarmac surfacing, and then for spreading the tarmac. The use comprised one 10-minute period of removing material, shovelled into the bucket by other workers, to a skip about 20m away along a metalled roadway **(not analysed)**. This involved considerable shaking to empty the bucket into the skip. The machine was then unused for half an hour. It was then used for spreading and levelling the tarmac. This was intermittent as the operator left the machine frequently to help with hand spreading.

The same operator also used a Bomag 2-drum roller to finish the tarmac surface.

All the surfaces were hard. Most of the running was on smooth tarmac road, with some on old driveway foundations that were smoothed by the operation of the machine itself.

Operational Record:-

Recording started: **10:30 hrs** **Duration:-** **2:15 hrs:mins**
Recording stopped: **12:45 hrs**

Data Analysis Period: **11:14 – 12:38 hrs** **Analysis Duration:** **1:25 hrs mins**

Time (hrs:mins)	Duration (hrs:mins)	Activity : Comments
10:31	**0:00**	Recorders started. Machine started. Operator uses bucket, pulled backwards across ground, to loosen material, then drives forward to fill bucket, with help of second man shovelling. Spins machine; drives to skip (20m); spins machine; raises bucket over skip and shakes to empty; reverses, spins and returns to worksite. This is repeated 4 times.
10:39	**0.08**	Switches machine off. TEAC recorder switched off.
11:14	**0:43**	TEAC recorder re-started. Machine re-started. Another load of surface material shovelled and taken to the skip, followed by a pause.
11:23	**0:52**	Another load of surface material shovelled and taken to the skip, followed by a pause.
11:36	**1:05**	Tarmac delivery. Machine started to move out of the way. Engine left running.
11:40	**1:09**	Uses bucket to spread the first heap of tarmac about the gateway.
11:43	**1:12**	Spreading tarmac by hand
11:53	**1:22**	Machine moved to allow access for more tarmac to be delivered.
11:59	**1:28**	Uses bucket to spread second heap of tarmac.
12:01	**1:30**	Spreading tarmac by hand
12:05	**1:34**	Uses bucket to spread more of second heap of tarmac
12:06	**1:35**	More spreading by hand.
12:10	**1:39**	Machine used to clear more of the old surface material
12:11	**1:40**	More spreading by hand
12:17	**1:46**	Takes old material to skip. Returns to use bucket to spread more of the second heap of asphalt.
12:20	**1:47**	More hand spreading
12:29	**1:56**	Machine started to move out of the way.
		Operator uses Bomag 2-drum roller to finish surface.
12:38	**2:07**	A second operator moves the machine to park it 20m beyond the skip.
12:43	**2:12**	Recorders switched off.


Figure A1.15.1 Site Operation

A1.15.2 Caterpillar 236 Skidsteer Loader: Whole-Body Vibration Data

Larson Davis HVM100	SN:00385	Day	Month	Year
Location:	***Floor***	***22***	***Mar***	***5***
Machine:	Compact wheel loader CAT 236			
Reg No:	122772 (fleet no)		Start time:	11:14
Task:	Moving / levelling asphalt			
Place:	Hagley			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
01:25	**7.7**	**5.5**	**13.5**	**16.5**
8-hr est tot	*11.9*	*8.5*	*20.8*	*25.4*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.38	***0.24***	***0.34***	***0.56***

Estimated values	**VDV**	**rms/A8**
Time to EAV (hr):	0.3	13.7
Time to ELV (hr):	8.3	72.7

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
5.56	5.19	20.00	19.90

Larson Davis HVM100	SN:00386	Day	Month	Year
Location:	***Seat***	***22***	***Mar***	***5***
Machine:	Skidsteer loader CAT 236			
Reg No:	122772 (fleet no)		Start time:	11:14
Task:	Moving / levelling asphalt			
Place:	Hagley			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
01:25	**8.8**	**6.1**	**15.9**	**19.2**
8-hr est tot	*13.6*	*9.4*	*24.5*	*29.5*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.44	***0.28***	***0.58***	***0.77***

Estimated values	**VDV**	**rms/A8**
Time to EAV (hr):	0.2	6.0
Time to ELV (hr):	4.3	32.0

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
5.94	5.39	27.90	27.90

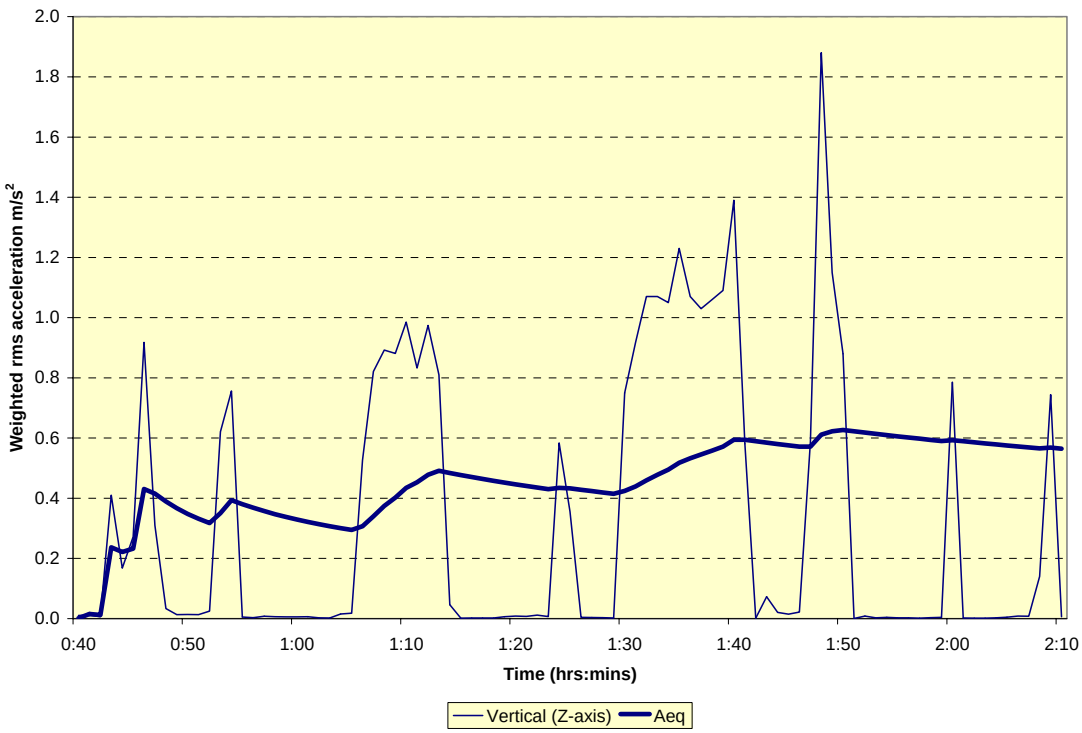

Figure A1.15.2 CAT Skidsteer Loader:- time history of weighted 1-minute rms seat accelerations (Z-axis) and equivalent continuous rms acceleration (Aeq)

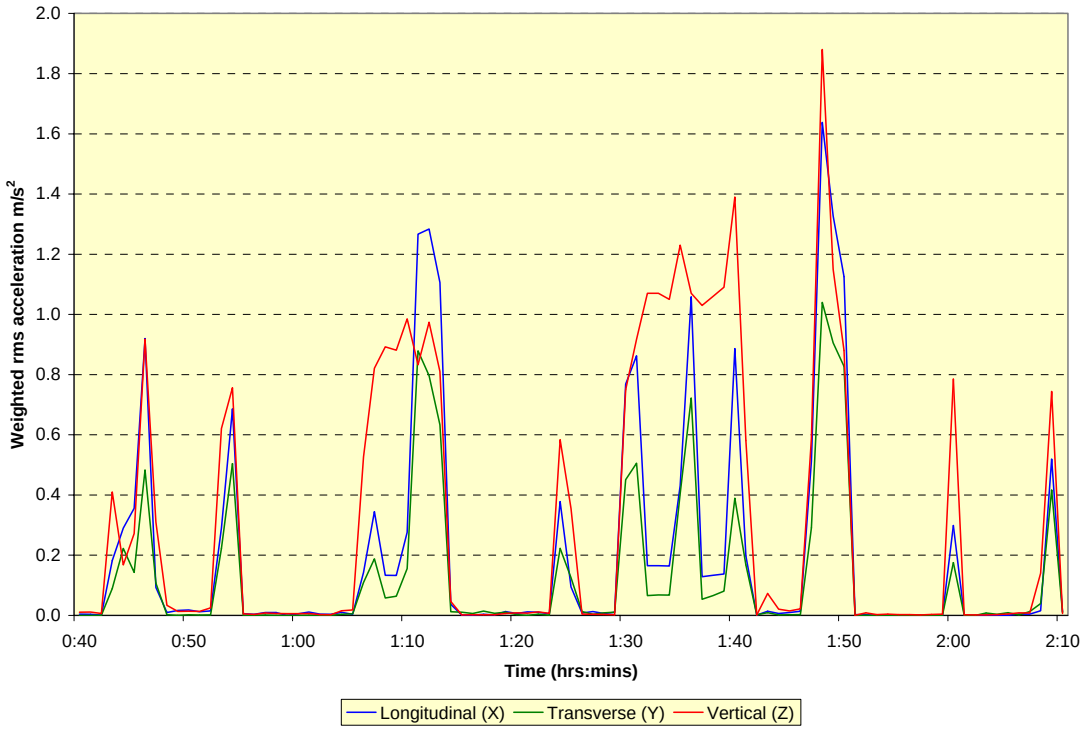

Figure A1.15.3 CAT Skidsteer Loader:- time histories of weighted 1-minute rms seat accelerations (X, Y and Z-axes)

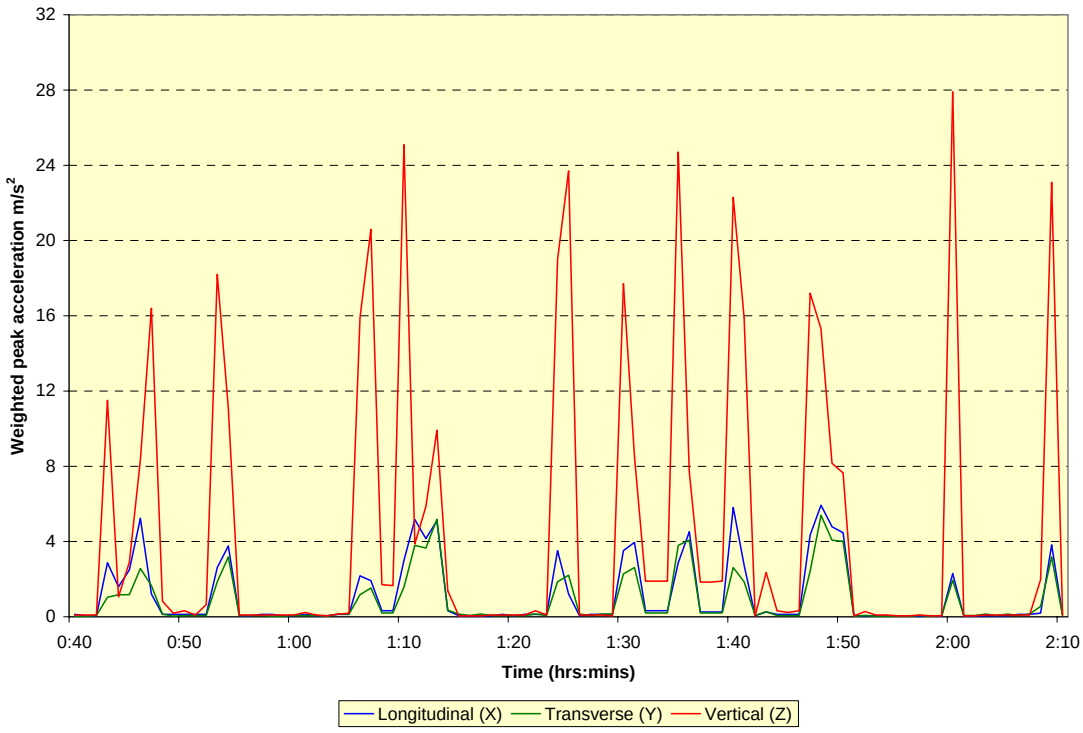

Figure A1.15.4 CAT Skidsteer Loader:- time histories of weighted 1-minute peak seat accelerations (X, Y and Z-axes)

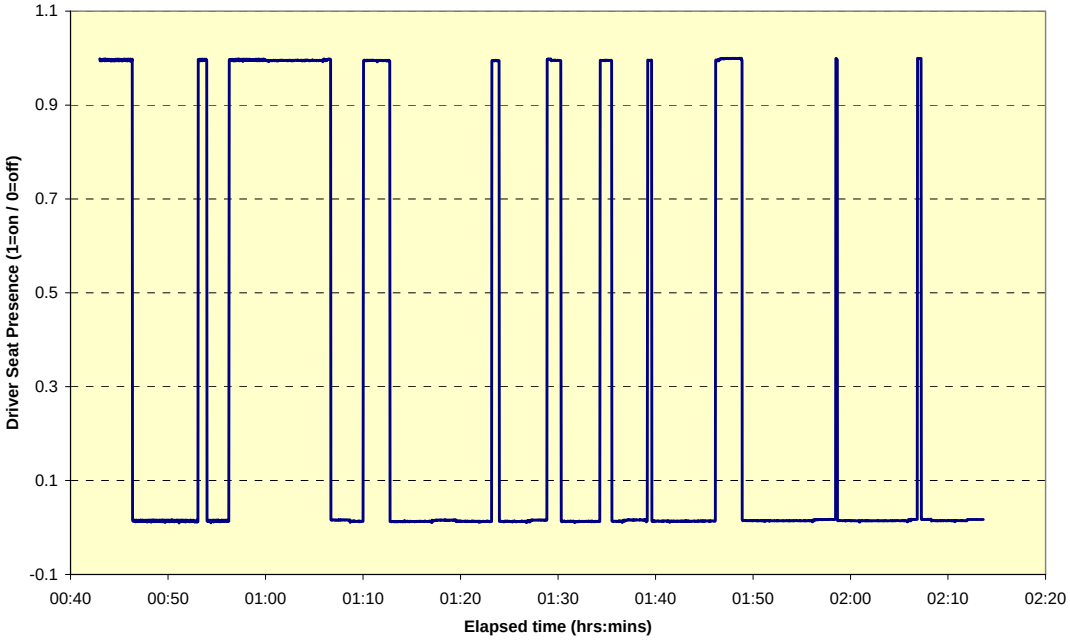

Figure A1.15.5 CAT Skidsteer Loader:- driver seat presence time history

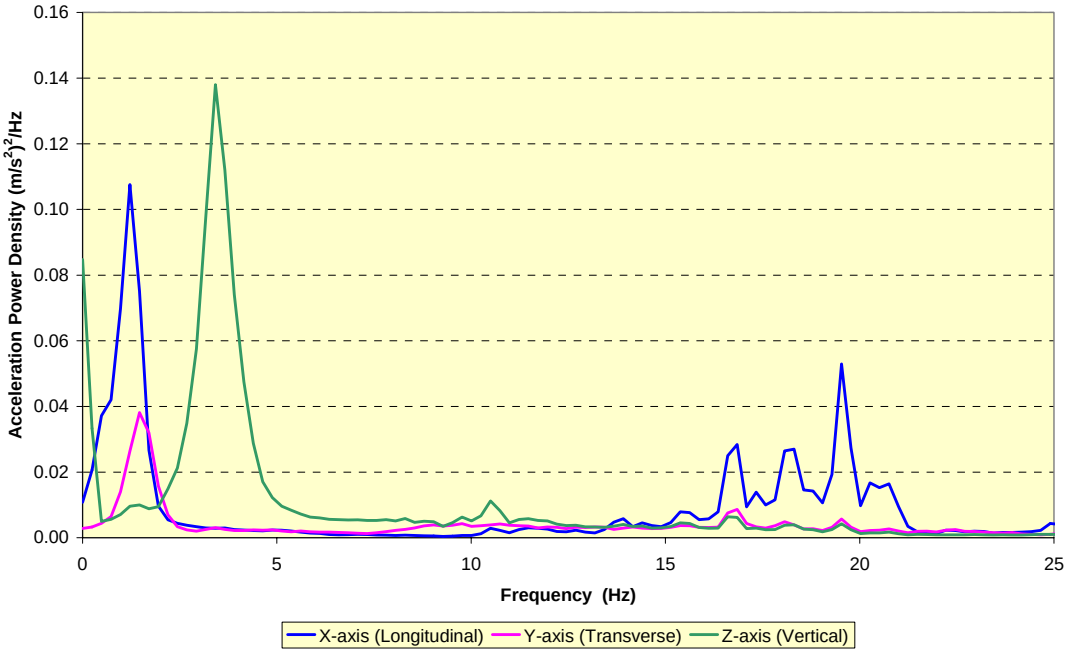

Figure A1.15.6 CAT Skidsteer Loader:- acceleration power spectral density (seat)

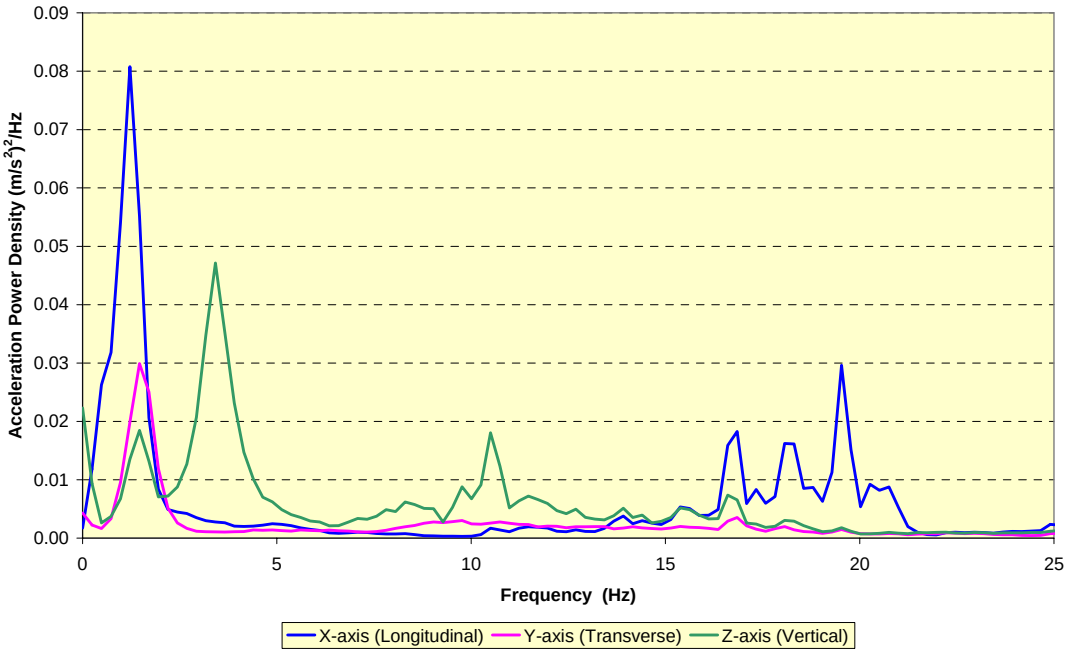

Figure A1.15.7 CAT Skidsteer Loader:- acceleration power spectral density (floor)

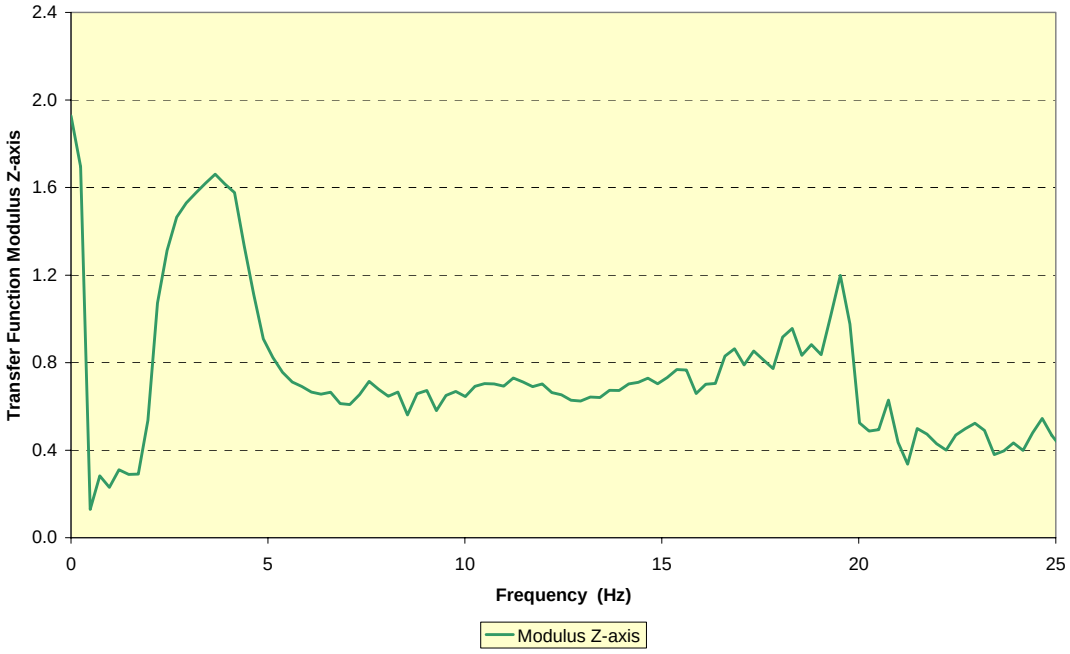

Figure A1.15.8 CAT Skidsteer Loader:- seat transfer function – Magnitude

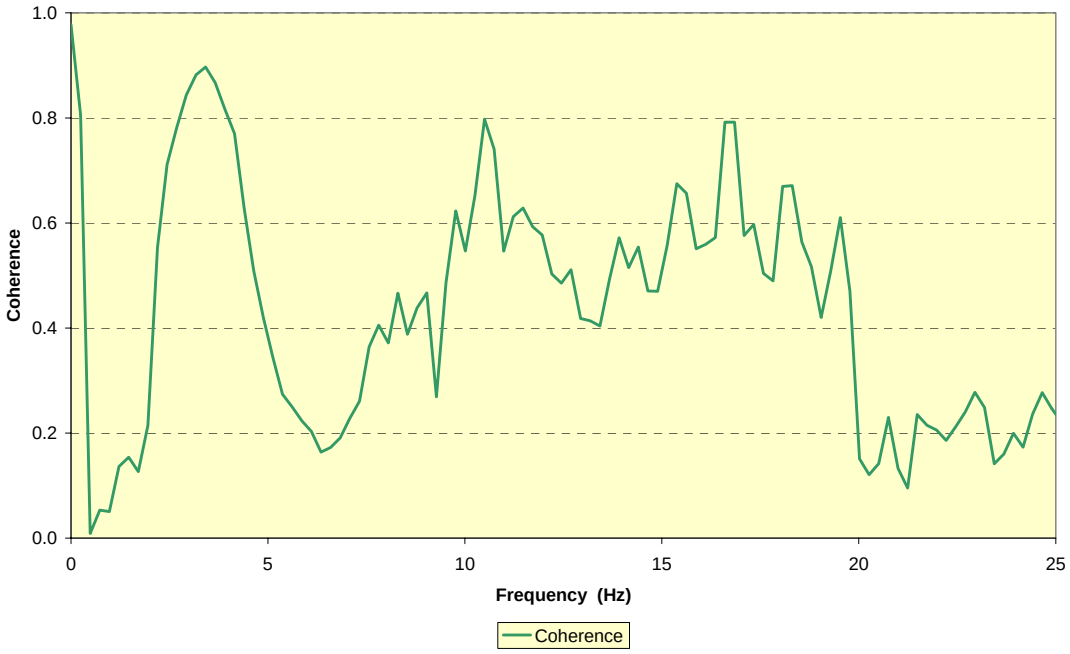

Figure A1.15.9 CAT Skidsteer Loader:- seat transfer function – Coherence

Appendix 1.16: Machine No.16 – Caterpillar 631G Wheeled Scraper

A1.16.1 Operational Details

Date:	11th April 2005
Location:	Langeled Gas Receiving Site, Easington, Hull
Machine Details:	
Make:	Caterpillar
Model:	631G
Weight:	44.25 Tonnes
Capacity:	36.25 Tonnes
Power:	365 kW
Registration:	
VIN/Serial No:	CAT0631GJCMT00213 Fleet No 3006
Year of build:	
Condition:	Good
Tyre size/make:	Michelin 37.25R35 XTS
Tyre pressures:	.
Vehicle Suspension:	None.
Seat Suspension:	Sears mechanical suspension. Condition good. Weight setting within operating range.
Owned and Operated by:	C.A. Blackwell Ltd.
Operator:	Weight 75 kg , Height 1.78 m.

WBV Instrumentation (transducers):

Seat:-	ICP type PCB 356B40 in seat pad plus operator seat presence switch
Floor: -	ICP type PCB 356B40 attached by magnetic clamp next to seat mounting bolt.

Site Operations:-

The operation on the day of measurement was to move topsoil from a temporary mound, within the site to be levelled, to form a new bank between that site and the nearby village, using three wheeled scrapers and two crawler dozers. The work cycle for each scraper involved (1) picking up from the heap (see sketch plan), with the aid of a crawler dozer pushing on the rear of the unit; (2) travel across a "land bridge" to the area of the new bank, a distance of about 150 to 200m; (3) dropping the material while moving across the bank area, which usually needed the aid of a second crawler dozer; and (4) Return to the pick-up area. During the return run the scraper blade would often be used as a grader to smooth either the new bank or the haul route. Each cycle took about 8 minutes, including some waiting time because the length of the haul route and the time required for picking up the material could not be matched precisely to the number of scrapers, or waiting for another machine to clear the "land bridge" [The "land bridge" provided the only secure route across a run of cables and pipes]. These delays varied from zero up to two minutes in a cycle. The surface was soil that had been run over by numerous machines during the levelling operation. Wheel ruts were removed by using the scrapers themselves as graders during the empty leg of the work cycle.

On the day of measurement, a full 11 hour shift was worked. It was expected that the operation would be completed sometime during the next day, resulting in less than 11 hours exposure, and the following days would see the machines transferred to another site. Work during the preceding week had mostly been for less than 11 hours a day, because of poor weather conditions.

Operational Record:-

Recording started: **11:44 hrs** **Duration:-** **3:13 hrs:mins**
Recording stopped: **14:57 hrs**

Time (hrs:mins)	Duration (hrs:mins)	Activity : Comments
11:45	**0:01**	Machine started and moved off.
11:48	**0:03**	Starts first pick-up
13:35	**1:50**	Delay while second crawler dozer is brought in to assist the pick-up stage of one of the other scrapers.
13:45	**2:00**	Resumes pick-up
14:54	**3:09**	Machine parked at end of work period. Total of 23 cycles completed in 190 minutes. .

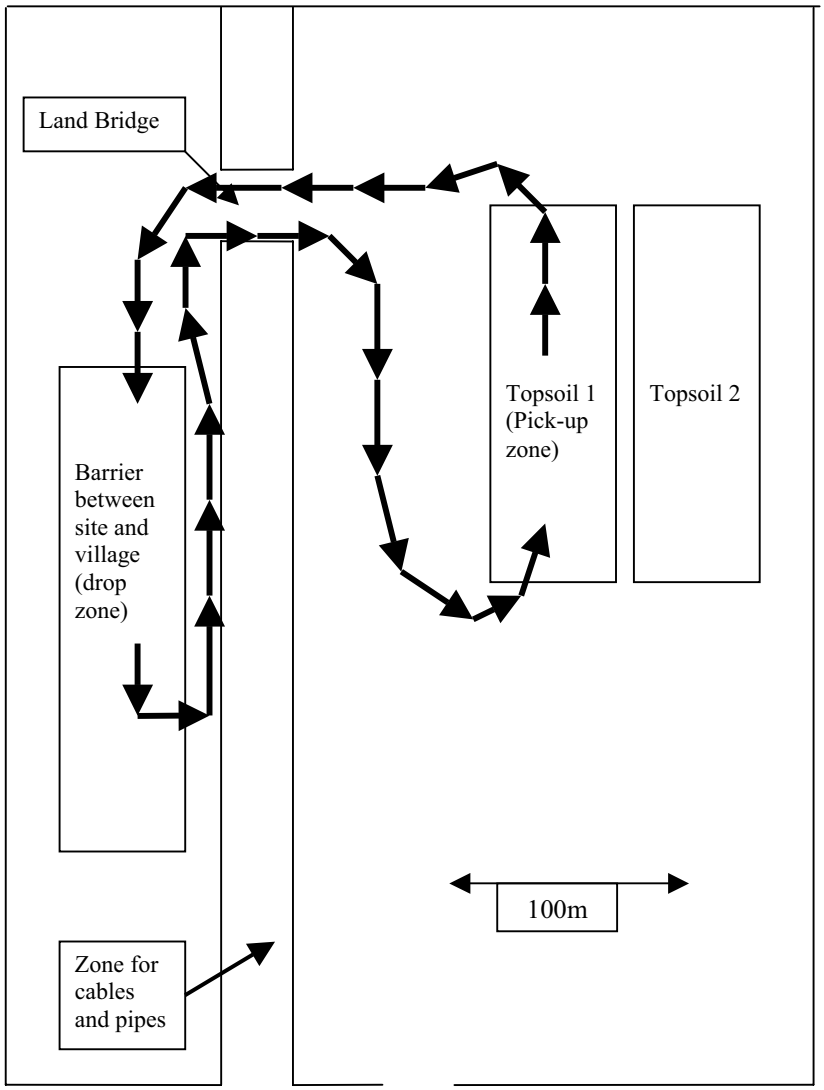

Figure A1.16.1 Sketch Plan of Site

Figure A1.16.2 Site Operation

A1.16.2 Caterpillar 631G Wheeled Scraper: Whole-Body Vibration Data

Larson Davis HVM100	SN:00385	Day	Month	Year
Location:	***Floor***	***11***	***Apr***	***5***
Machine:	Scraper (CAT 631G)			
Reg No:	3006		Start time:	10:39
Task:	Moving Soil (Cut & Fill)			
Place:	Easington			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
03:14	**13.7**	**11.8**	**9.6**	**20.5**
8-hr est tot	*17.2*	*14.8*	*12.0*	*25.6*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.75	***0.68***	***0.48***	***1.12***

Estimated values	**VDV**	**rms/A8**
Time to EAV (hr):	0.6	3.5
Time to ELV (hr):	17.8	18.7

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
7.71	7.45	7.55	9.32

Larson Davis HVM100	SN:00386	Day	Month	Year
Location:	***Seat***	***11***	***Apr***	***5***
Machine:	Scraper (CAT 631G)			
Reg No:	3006		Start time:	10:38
Task:	Moving Soil (Cut & Fill)			
Place:	Easington			

Total VDV (m/s $^{1.75}$)

Time	X	Y	Z	Sum
03:14	**17.5**	**17.2**	**12.5**	**27.5**
8-hr est tot	*21.9*	*21.5*	*15.7*	*34.5*

Average r.m.s. (Aeq) (m/s ^{2})

X	Y	Z	Sum
0.96	***0.97***	***0.64***	***1.51***

Estimated values	**VDV**	**rms/A8**
Time to EAV (hr):	0.2	2.1
Time to ELV (hr):	6.7	11.2

Maximum peak value (m/s ^{2})

X	Y	Z	Sum
10.71	8.76	10.10	14.40

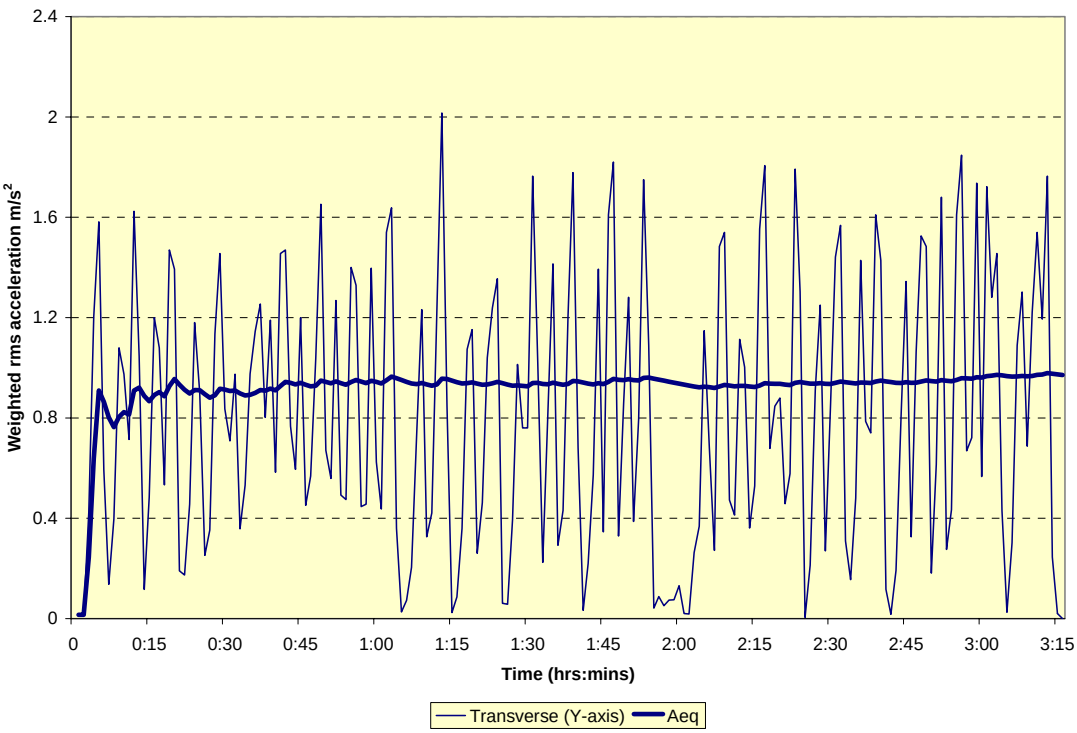

Figure A1.16.3 CAT Wheeled Scraper:- time history of weighted 1-minute rms seat accelerations (Z-axis) and equivalent continuous rms acceleration (Aeq)

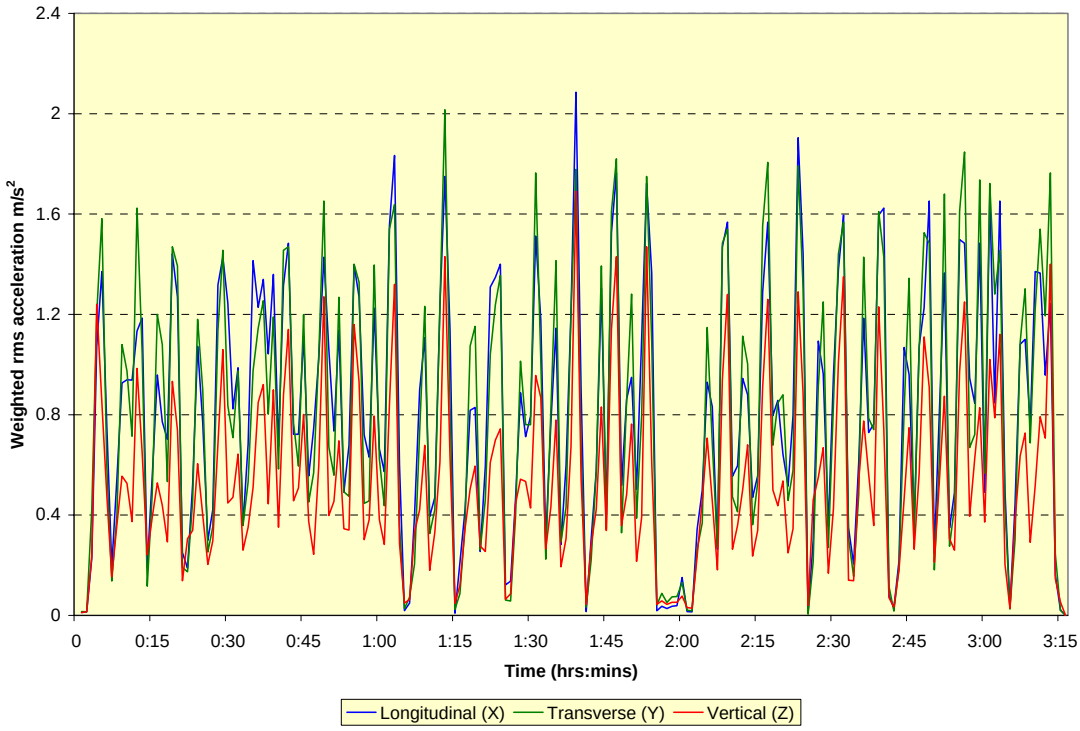

Figure A1.16.4 CAT Wheeled Scraper:- time histories of weighted 1-minute rms seat accelerations (X, Y and Z-axes)

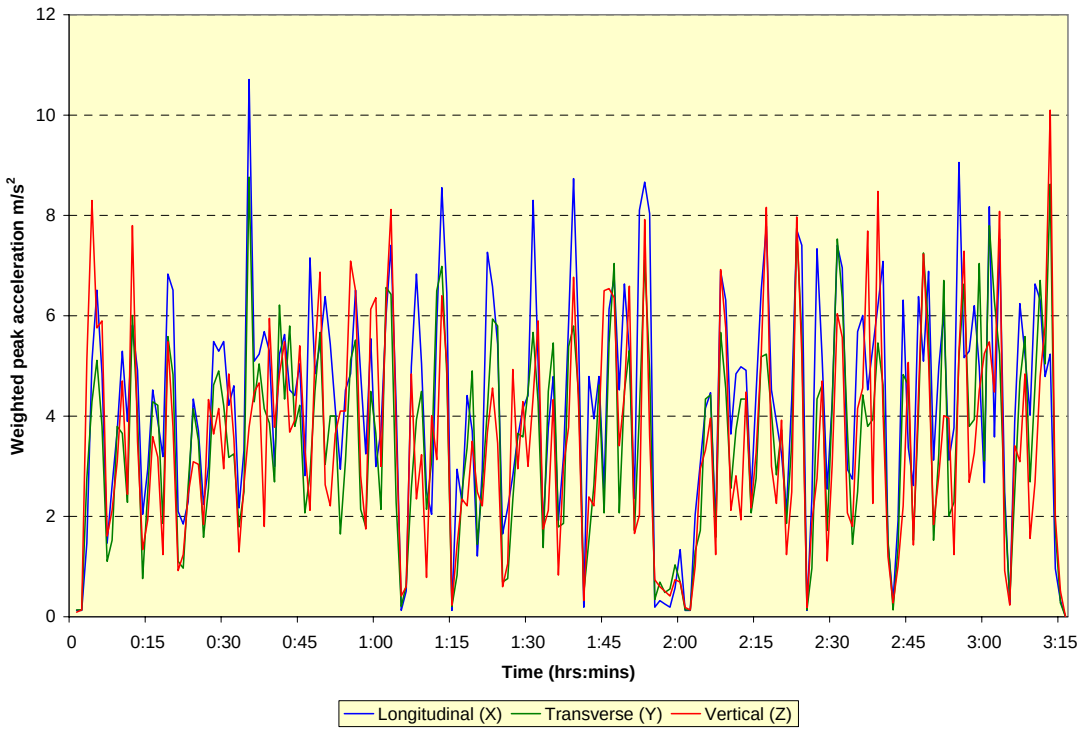

Figure A1.16.5 CAT Wheeled Scraper:- time histories of weighted 1-minute peak seat accelerations (X, Y and Z-axes)

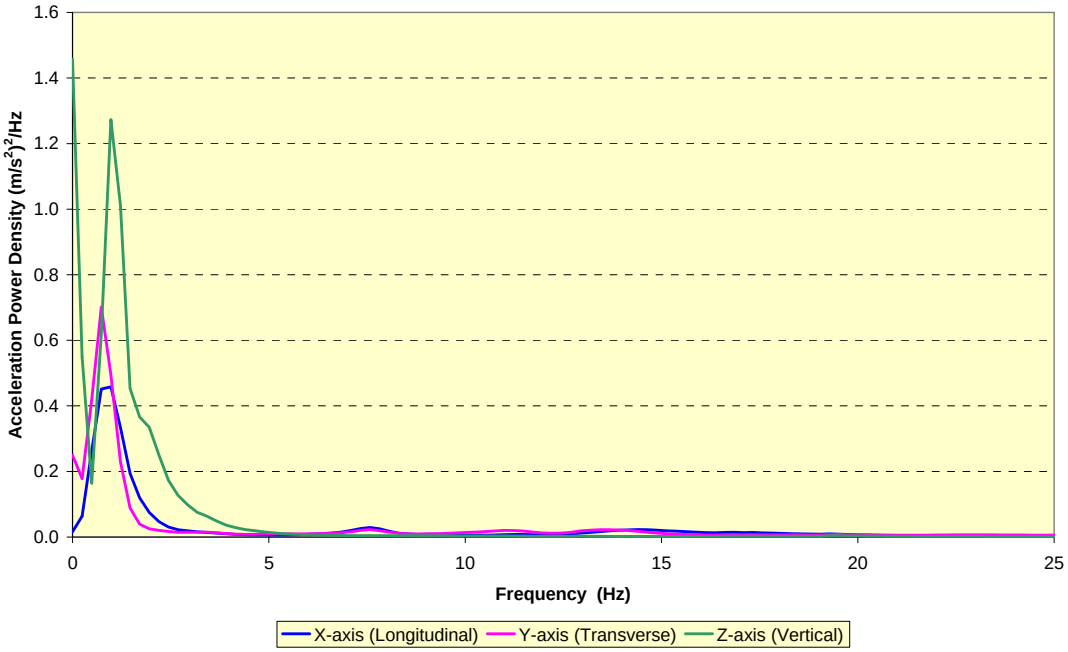

Figure A1.16.6 CAT Wheeled Scraper:- acceleration power spectral density (seat)

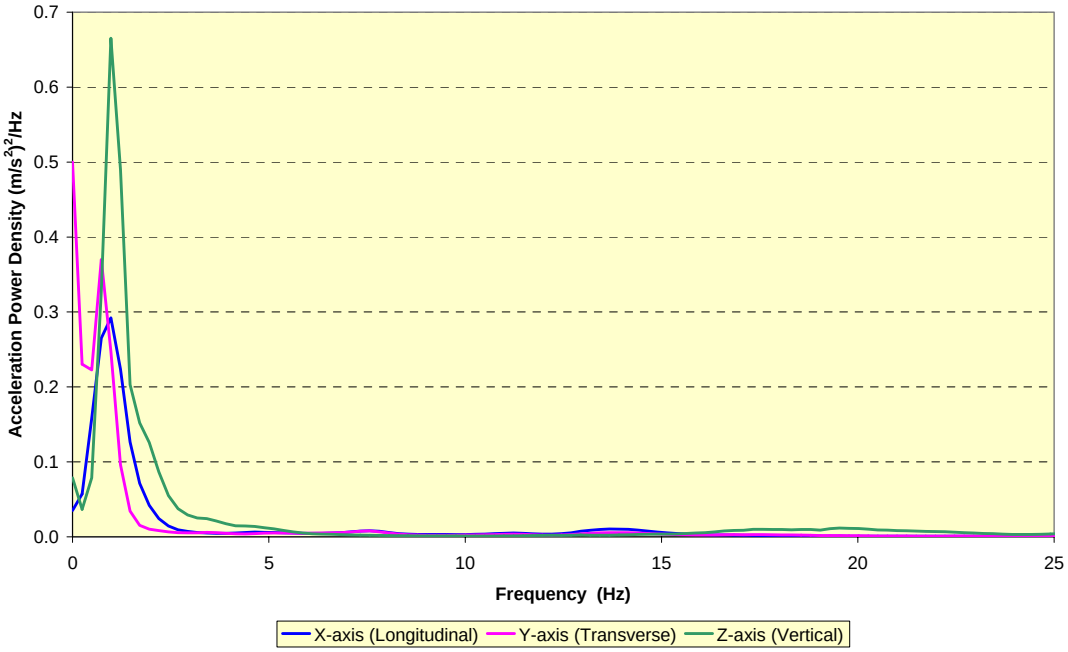

Figure A1.16.7 CAT Wheeled Scraper:- acceleration power spectral density (floor)

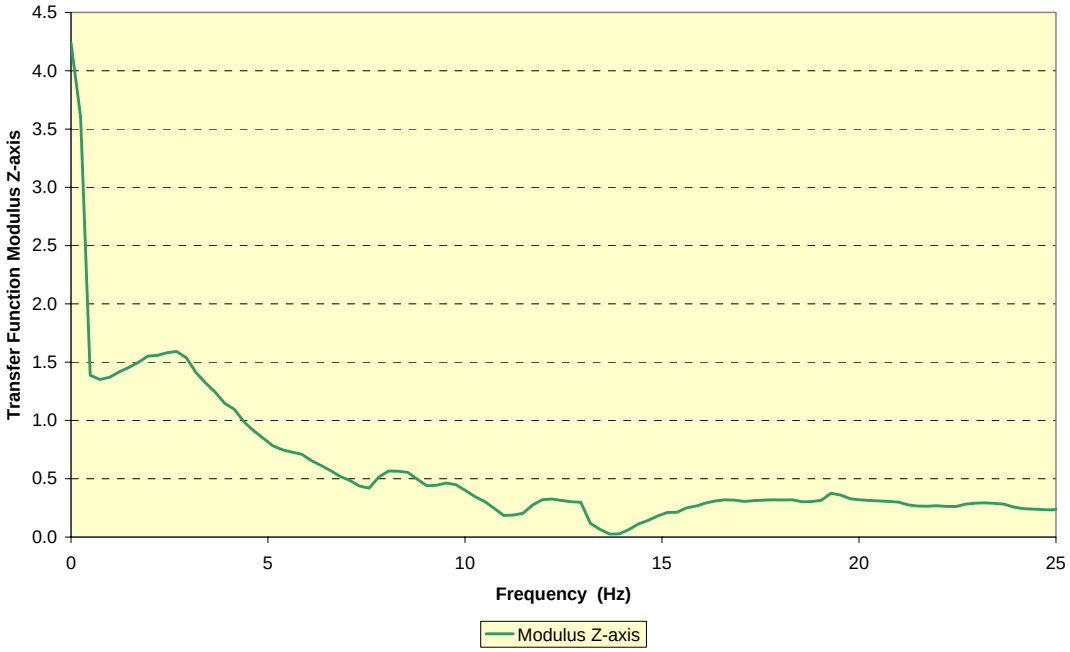

Figure A1.16.8 CAT Wheeled Scraper:- seat transfer function – Magnitude

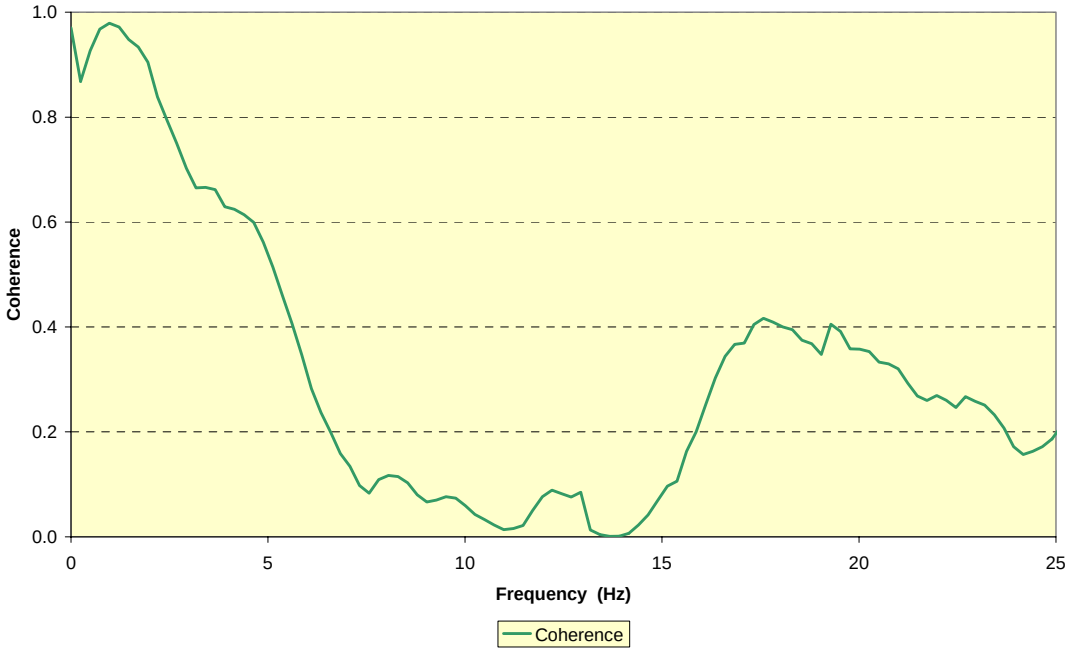

Figure A1.16.9 CAT Wheeled Scraper:- seat transfer function – Coherence

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