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INTERNATIONAL SAFETY PANEL

RESEARCH PAPER # 12

THE EFFECTS AND MANAGEMENT OF WHOLE BODY VIBRATION AS A STRESSOR IN THE PORT INDUSTRY

By

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CONTENTS **PAGE**

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WHOLE BODY VIBRATION

1 INTRODUCTION

1.1 Background

1.1.1 A high incidence of low back pain among port plant operators has been recognised for some time. In the 1970's low back pain became prevalent among container terminal tractor drivers in Japan (Nishiyama K. *et al* 1998). The prevalence of low back pain was found to be 50% of crane operators and 44 % of straddle carrier operators as opposed to 34% of office workers in a Rotterdam study. (Burdorf A. *et al* 1993).

1.1.2 Low back pain can be attributed to a number of factors such as bad equipment design, poor ergonomic design of the operating cabs, poor seating or the lack of adjustment, inappropriate work station design, manual handling, posture and the characteristics and age of the employee. Another possible factor causing or exacerbating this low back pain is exposure to whole body vibration.

1.1.3 The significance of the effect of vibration on the low back pain experienced by plant operators as opposed to the effects of bad posture, which is a well recognised problem for the operation of port plant and remains without complete solution, is not fully understood (Bovenzi 2002). Neither is the general concept of vibration as a physical stressor in the workplace one that is readily accepted.

1.1.4 A survey carried out on behalf of the author resulted in a less than enthusiastic response which may show either a lack of knowledge of WBV or an apathy to the suggestion that it may be a significant stressor within the port industry or elements of both.

1.1.5 Plant such as fork lift trucks, loaders, mobile cranes and tractors are listed by the UK Health and Safety Executive as "Exposure Sources" in a contract report on the effects of WBV (Palma K. *et al* 1999); straddle carriers are added to this list in the publication "In the Driving Seat".

1.1.6 This equipment used in ports is often of high value and its efficient operation depends upon good training and a large degree of acquired skill. The port industry cannot afford to lose this developed skill through injury, neither can it tolerate inefficiency in its use because the operators are put under unnecessary stress. Added to this there is a high degree of emphasis on health and safety promotion within the port industry.

1.1.7 With the advent of a European directive and national legislation in Europe to control whole body vibration as a physical agent capable of causing or exacerbating injury, there is a need in the port industry for understanding of the stressor itself, how to assess the risks from it, how to recognise its effects, how to comply with legislation and more important how to minimise the risk of injuries caused by it, so that the industry can operate its high value plant in an efficient manner and maximise the health of its employees.

1.2 Aim

1.2.1 The project aims to fulfil that need by exploring the relevance of whole body vibration within the international port industry and developing industry guidance on controlling the risks from it and presenting the information in a form that is readily understood and can easily be put into practice by the port industry.

1.3 Objectives

1.3.1 To review the likely adverse health effects of exposure to whole body vibration specifically within the port industry.

1.3.2 To explore the possible means of assessing risks, both with and without vibration measurement and/or expert assistance.

1.3.3 Explore possible methods of health surveillance and monitoring, and develop industry guidance for its implementation.

1.3.4 To explore the various means by which improvements may be achieved with respect to plant, equipment, the workplace and working methods and, where necessary, stimulating technical development in order that the risks to the health of port workers are minimised.

2 WHOLE BODY VIBRATION

2.1 What is Whole Body Vibration (WBV)?

2.1.1 Vibration itself is any oscillatory motion of a particle or a body, to and fro about a fixed position.

2.1.2 Whole Body Vibration (WBV), in the context of this study, is vibration that is transmitted to the human body as a whole from work related machinery, either through the buttocks of a seated person or through the soles of the feet of a standing person. Such transmitted vibration sets up corresponding vibration with the human body which can have an effect on its structure or its functions and consequently on the individual and his health and well-being.

2.1.3 The term Whole Body Vibration excludes vibration that is transmitted to the hands and the arms due to hand contact with vibrating tools and surfaces. This is known as Hand-Arm vibration and has a specific well understood effect of the hands and fingers. Hand-arm vibration is not included in this study.

2.1.4 From an occupational health perspective, WBV can affect to greater or lesser degree a standing or seated operator of vibrating plant or machinery or the driver of vehicles.

2.1.5 Vibration has measurable parameters that play vital roles in the way in which it has an effect on the body. The rate at which the particle or body oscillates is its frequency and is measured in cycles per second or Hertz (Hz). The physical distance moved during vibration is known as the amplitude and is measured in millimetres.

2.1.6 In order for the movement to take place back and forth over the distance, in the time allowed by the frequency of the oscillation, the body must be subjected to an acceleration - first in one direction and then the opposite. This is repeated throughout the duration of the vibration. It is this acceleration (or its RMS value, measured in metres per second squared- m/s^2) that is measured in order to ascertain the degree or strength of the vibration. The symbol used universally for this RMS acceleration is "a".

2.1.7 In order that this vibration acceleration be related to its effect on the human body, especially for the purposes of risk assessment, frequency weightings (Figure 2.1) are applied to the basic RMS acceleration value. This basically has the effect of suppressing readings outside the 0,5 to 80 Hz frequency range (The range that is recommended in ISO 2631-1). This is a similar principle to the A weighting (dBA) applied to noise level measurements when assessing the likely adverse effect of noise on a persons hearing ability. Acceleration however, unlike noise, is not normally expressed on logarithmic scale. This modified (weighted) acceleration value is referred to as "a_w". Tables of the appropriate frequency weightings are provided in ISO2631-1 1997 and a graph depicting the effect of the main weightings is found in Figure 1 below.

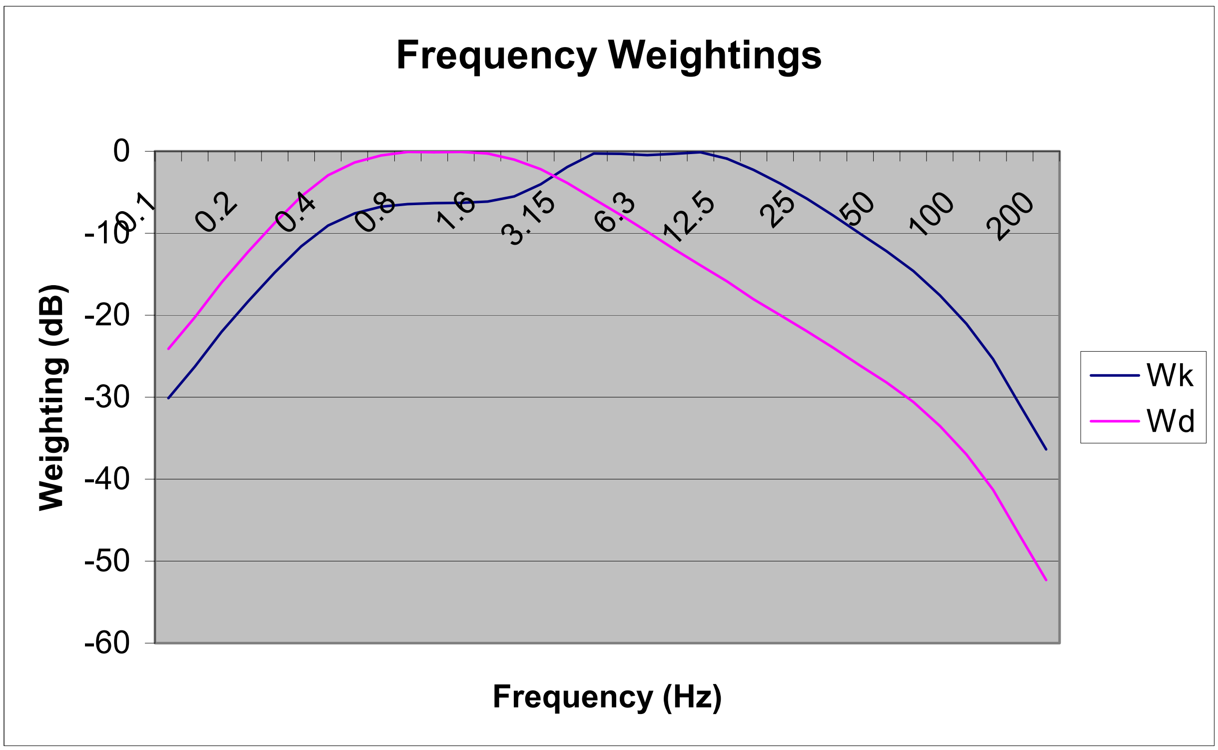

Figure 1

2.1.8 Modern vibration measuring instruments, especially those designed specifically for the measurement of vibration to which human bodies are exposed, normally have these "weightings" built into their signal conditioning circuitry thus giving a direct readout of the frequency weighted RMS acceleration.

2.2 What are its effects on the human body?

2.2.1 Vibration transmitted to the body in the way described sets in motion various organs and musculo-skeletal parts of the body, with varying effects depending on its frequency and acceleration.

2.2.2 The symptoms experienced by the person exposed can vary from a mild discomfort to physical pain, having acute (transitional), or possibly chronic (long term) effects.

2.3 Discomfort

2.3.1 One effect may be that of discomfort, but the prediction of exactly what frequency and acceleration is likely to cause it, is somewhat vague. Indeed what may be unacceptable to one person may well be exhilarating to another.

2.3.2 ISO 2631-1 gives an indication of the likely degree of discomfort experienced for varying levels of acceleration (Table 1). The frequency range and weighting factor used when measuring acceleration for the purpose of assessing discomfort are the same as those used for assessing long-term health effects.

less than 0.315 m/s^2	Not uncomfortable
0.315 - 0.63 m/s^2	A little uncomfortable
0.5 - 1.00 m/s^2	Fairly uncomfortable
0.3 - 1.6 m/s^2	Uncomfortable
1.35 - 2.5 m/s^2	Very uncomfortable
Greater than 2.0 m/s^2	Extremely uncomfortable

Table 1 - Perception of Vibration

Discomfort is transitional and exists only while the vibration continues. There are no long term effects.

2.4 Motion sickness

2.4.1 Motion sickness may be experienced at very low frequencies, those of 0.5 Hz or less, which many people may not consider to be vibration at all.

2.4.2 An individual's susceptibility to motion sickness again varies widely and indeed, over long periods of exposure, adaptation to the vibration often occurs. This adaptation is retained by some individuals, reducing their susceptibility to further similar motions.

2.4.3 Again motion sickness is an acute effect of vibration and although it is unpleasant, recovery follows a short period after the exposure to vibration ceases.

2.5 Longer term health risks

2.5.1 There is gathering opinion that exposure to WBV may have chronic effects on health. The extent of these is not yet fully understood but includes such effects as tiredness, headache, depression, digestive disorders, impotence and more importantly for this study lower-back related pain.

2.5.2 It is the latter that has been the subject of most of the studies relating to WBV and is becoming related to exposure to WBV as the possible workplace stressor. Low Back Pain therefore will be the main effect of WBV concentrated upon in this study.

2.5.3 It is considered that any best management practices developed by this study, although aimed at minimising low back problems, will be sound in relation to all other long term effects of WBV.

2.6 Present knowledge and understanding

2.6.1 Various investigations have shown (ie. Bovenzi M 1999) that the adverse health effects of WBV can occur in the frequency range of 0.5 Hz to 80 Hz.

2.6.2 These adverse effects can include disorders of the lumbar spine, neck/shoulders, gastro-intestinal systems, female reproductive organs, peripheral veins and the cochleo-vestibular system. However the only adverse effects with credible epidemiological support, are the disorders of the lower back.

2.6.3 A study of tractor-driving farmers, (tractor drivers are known to be exposed to high levels of vibration) (Kuma A *et al* 1999), concluded that the group was more prone to lower back pain than the control group of non-tractor-driving farmers, although no difference in degeneration was detected during clinical and magnetic resonance imaging (MRI) tests.

2.6.4 Another investigation in Finland (Battie C *et al* 2002), where sets of driving and non-driving monozygotic twins were compared, had similar findings – a higher rate of symptoms (LBP) but little evidence of physical deterioration.

2.6.5 It is therefore assumed that the major aim of any effort to reduce exposure to whole body vibration must be to reduce the occurrence of low back pain symptoms. A study of freight container tractor (tug) drivers (Nishiyama *et al* 1988) showed that reducing the WBV levels to which the drivers were exposed reduced the incidence of low back pain (LBP) which clearly indicates that, from a commercial and a sociological point of view, it is sensible to reduce workers exposure to WBV so far as reasonably practicable.

2.7 Main items of plant used in the port industry and their effects

2.7.1 The main items of equipment are:

- Container tractors (Tugs)
- Quay (overhead) cranes
- Straddle carriers
- Rubber-tyred gantry cranes
- Lift trucks (FLT, empty container handlers etc.)

2.7.2 A study of LBP in port machinery operators (Bovenzi M. 2002) found the prevalence of low back symptoms increased as the exposure to WBV increased. The highest WBV levels were from forklift trucks and correspondingly the incidence of low back pain was significantly higher among FLT drivers.

2.7.3 This is surprising when considering the ergonomic and postural problems to which an overhead crane driver is exposed, ie leaning forward and looking down between his legs in order to guide the crane spreader on to containers some 30 metres or more directly below, and tends to indicate that WBV may be an independent and significant predictor of LBP as well as exacerbating the effects of bad posture.

2.7.4 The fact that Bovenzi found the z (vertical) axis (see Figure 3) on the FLT has the predominant acceleration, is also surprising as horizontal (x and y) vibrations are generally considered to have more effect on the low back symptom than the vertical axis acceleration. (Nishiyama k. *et al* 1998). In Nishiyama's findings, peaks are recorded on the seats at between 1.25 Hz - 5 Hz (at Felixstowe, peaks between 1.1 Hz and 3 Hz have been recorded).

2.7.5 Experiments have shown that for a seated person the lumbar region of the spine has a resonant frequency of between 2 and 6 Hz in the z axis. At the resonance frequency, relative displacement takes place between the vertebrae compressing and relaxing the intervertebral discs amplifying (intensifying) the vibration by up to 200% (USACHPPM undated) In the instance of the FLT drivers "overload" in this displacement may be taking place, resulting in the symptoms.

2.7.6 The incidences of low back pain cannot be measured - they are reported by the person involved normally via health questionnaires. It is therefore subjective information and may be confounded by such things as job satisfaction, reward structure and status. With respect to Bovensi's (2000) report, it may be that fork lift drivers are at the lower end of the port labour scale and that quay crane drivers are at the higher end with high pay, status and job satisfaction. It also may well be that tasks which have known ergonomic and postural problems have increased management controls to limit exposure times.

2.7.7 I conclude therefore that as well as exacerbating the effects of static loading, twisting and bad posture WBV may be an independent predictor for low back pain, causing acute trauma and possible over time causing chronic deterioration although there is no proven clear exposure/response relationship.

2.8 Scope of this study

2.8.1 While the discussion goes on amongst the medical profession as to why, what and how much the effects of vibration causes onset or the exacerbation of low back pain, it is important that the port industry - with fairly high numbers of employees suffering such pain - takes steps to minimise the risks from WBV.

2.8.2 Hence this study attempts to identify the likely areas of risk, the levels of vibration to which employees are exposed and the possibilities for improvement, so that port employers may assess the risk to their employees sufficiently and then prioritise and implement actions to reduce risk and monitor those at risk.

2.9 Likely Sources of WBV

2.9.1 Taking the "action value" from the European directive on vibration as a guide (ie an 8-hour weighted average RMS acceleration "a_w 8"of 0.5 m/s^2), it would appear that any vehicle or item of plant which is likely to transmit to the driver or operator more vibration than would be experienced by the driver of an ordinary automobile when used on well maintained roads, is likely to require a programme for assessing and managing the risk.

2.9.2 This broad view will encompass the drivers of most vehicles and plant in a modern port to a greater or lesser degree. The types of equipment will include container terminal tractors, Ro-ro terminal tractors, container cranes, forklift and clamp trucks, reach stackers, straddle carriers, excavators, bobcats, empty container handlers, rubber-tyred gantry cranes and others. Of these the most important for consideration are those that expose the operator to shock vibration (individual high acceleration event), the lump and bumps. From information gathered or measurement taken these will include such items as straddle carriers, Ro-ro terminal tractors, empty container handlers, bobcats, forklifts, clamp trucks and excavators.

2.9.3 Some items, such as container quay cranes and rubber-tyred gantry cranes, may well fall below this "action value" providing that trolley rails and boom joints are well maintained. Indeed it was the view of M Burdorf *et al* that the most significant factor causing low back pain among crane and straddle-carrier drivers was that they adopted a "non-neutral posture" (ie seated and looking down between their legs to view the operation below) rather than WBV. (M Burdorf *et al* 1993) The probability that any effect of vibration on the spine is exacerbated by the bad posture remains a factor that should be considered.

3 REVIEW OF LEGISLATION

3.1 Existing international legislation

3.1.1 The recommendation for levels, limits and guidance on exposure to WBV in most countries is based upon ISO Standards. Either ISO 2631-1 1997 or the earlier ISO 2631-1 1985. ISO 2631-1 1985 provides methods for measuring Whole Body Vibration and for evaluating its likely affect on the health, comfort, perception and motions sickness experienced by those persons exposed to it.

3.1.2 The standard contains frequency weighting tables and factors which allow measurements to be modified so that they simulate the degree to which vibration level actual affect the human body whilst exposed in various postures to vibrations in acting various directions. It also contains graphical guidance in the form of a caution zone superimposed on a weighted acceleration /exposure duration graph.

3.1.3 Although Canadian jurisdictions have no specific regulations the ISO standards and recommendations and Threshold Value Limits (TVLs) set by the American Conference of Government Industrial Hygienists (which themselves are based upon ISO standards) would normally be applied.

3.1.4 In some jurisdictions workers compensation boards suggest the following TVL "boundaries" as guidelines -

Over 0.5 m/s^2 - Caution with respect to possible health risks

Over 0.8 m/s^2 - Health risks likely

3.1.5 Australian standards are based on the earlier ISO standard and appear on the face of it more stringent with the following limits. (Mabbott *et al* 2001)

Fatigue limit - 0.315 m/s^2

Health limit - 0.63 m/s^2

3.1.6 All these so called limits are guidance values. Only in the EU are there actual legally enforceable “limits” above which persons must not be exposed; these are incorporated in the Physical Agents (Vibration) Directive which came into force in July 2005 and required member states to incorporate the limits, or more favourable options, into their national legislation. The directive is also based on ISO 2631–1 1997 and includes options to use the more shock friendly Vibration Dose Values as well as the RMS acceleration value for quantifying vibration.

3.1.7 The values prescribed are:

a daily (8 hour) exposure limit - 1.15 m/s^2 (or VDV of 21 $m/s^{1.75}$)

a daily (8 hour) action value - 0.5 m/s2 (or VDV of 11 $m/s^{1.75}$)
(VDV is the Vibration Dose Value – see section 4.1.7**)**

As well as prescribing limit and action values the directive also gives a template for the development of a management strategy that will reduce WBV risks to the minimum levels practicable which can be applied globally.

3.2 Criminal and civil law implications for the port industry

3.2.1 Many countries have worker compensation regimes that include arrangements for compensating workers in respect to work related back injuries. Low back pain, the main injury considered to result from WBV, is among the world’s most common health problems although there is not always recognition of the fact that it could be WBV-related.

3.2.2 A list of occupational diseases compiled by the European Commission in 1990 did not include WBV injuries however the following countries do recognise it as such (Hulsof, C.T.J *et al* 2002) and have done so since the years shown below.

- Belgium – 1978
- Germany – 1993
- Netherlands – 1997
- France - 1999
- Japan - 1980

3.2.3 In Belgium it is referred to as “Bone and Joint Disorder cause by Mechanical Vibration” and is occupational disease No. 1.605:01. In France the National Illness Insurance Fund recognises it under a similar name as Tableau No. 97. In the Netherlands it is recognised as “Low Back Pain Due to WBV” and in Germany as disease No.2110.

3.2.4 The adoption of specific enforceable limits into the European Union directive and national legislation gives out a message that WBV is directly and positively connected with injury, and in particular low back pain, although a cause-and-effect relationship has not been positively proven. This message may well open the floodgates for compensation claims in the world's more litigious societies, in respect to an injury which is one of the world's most common and with links to causations which are possibly least understood.

3.2.5 As well as increasing the likelihood of compensation claims from employees, the European Physical Agents (Vibration) Directive (which came into force in July 2005) could also make employers liable to criminal prosecution if they ignore the risk of injury caused by vibration or fail to take steps to prevent or minimise it.

3.2.6 The directive itself deals with hand-arm vibration as well as whole body vibration, setting separate daily exposure action and limit values in each case whilst prescribing a common management procedure for controlling the risk to employees.

3.2.7 The prescribed management procedures include:

- Carrying out a risk assessment of the risks to employees' health or their ability to control machinery presented by vibration by observing work practices and ascertaining the vibration magnitude either from available information or by measurement using the methods and weighting values prescribed in ISO 2631, recording the findings and reviewing them regularly or after changes.

- Eliminating or controlling vibration exposure levels to as low as practicable, at least below the limit value, by technical or management means, where vibration is at or above the action value.

- Providing information and training to employees so they can understand the risks. Are able to use the equipment in the correct manner, can take steps to minimise risks to themselves and detect and take action on any symptom that may develop.

- Carrying out health surveillance in order to monitor the health of employees, monitor the management system in place and detect any likely problem areas.

4 MANAGING RISK

4.1 Risk assessment

4.1.1 The risk of injury or ill health from WBV as well as other stressors both chemical and physical, is a function of a person's exposure to that stressor. The greater the exposure, the greater the risk of injury or ill health.

4.1.2 Exposure depends not only on the magnitude of the vibration to which a person is exposed but also on the length of time during the working day that they are actually exposed to the vibration.

4.1.3 The common way of expressing such an exposure is an 8 hour energy equivalent frequency weighted acceleration:

$$\mathbf{a_w(8) = a_w \sqrt{t/8}}$$

where "t" is the actual duration of the exposure to the vibration in hours and $\mathbf{a_w}$ is the frequency weighted RMS acceleration level.

4.1.4 The calculation or estimation of the quantitative exposure gives the vibration equivalent of the daily dose value used for chemical or noise assessment. This value can then be compared with values considered to give rise to injury or ill-health, such as the action and limit values prescribed in the European directive, in order to assess the risk to the person exposed.

4.1.5 This $\mathbf{a_w(8)}$ does not however allow for the shock vibrations (lumps and bumps) which are considered to have greater adverse effect than a steady constant vibration. If the peak values of vibration ($\mathbf{a_w Pk}$) are measured as the peak weighted acceleration as well as the average RMS level then a crest factor can be calculated:

$$\text{Crest Factor} = \mathbf{a_{wpk} / a_{w\,rms}}$$

4.1.6 Generally the risk from shock vibration becomes significant when the crest factor is greater than 9 (ISO 2361-1).

4.1.7 Where this occurs a more accurate assessment can be made using the "fourth power" (Root Mean Quad or RMQ) instead of the RMS (second power) means of measurement. Such a method results in what is known as the Vibration Dose Value (VDV) which takes better account of the shocks and jolts than the $\mathbf{a_w(8)}$. This VDV measurement requires an instrument with a fourth power facility which integrates the weighted acceleration value using the following formula

$$\mathbf{VDV = \left\{ {}^{T}\!\int_{0} [a_w(t)]^{4}\, dt \right\}^{1/4} (m/s^{1.75})}$$

4.1.8 The resulting difference between the $\mathbf{a_w(8)}$ and the **VDV** can be seen in the following graph Figure 2) Note how the VDV curve rises every time a peak (shock) vibration occurs (at 5 seconds. 20 seconds and 35 seconds) on the RMS curve giving a higher VDV value as larger and more frequent peaks are detected while the RMS curve remains relatively constant.

4.1.9 The VDV takes better account of the shocks that are more like to cause harm.

4.2 Obtaining Vibration Values

4.2.1 In order to assess the risk presented to equipment operators by WBV in a sufficient manner the $a_w(8)$ (and /or the VDV) for the task must be ascertained.

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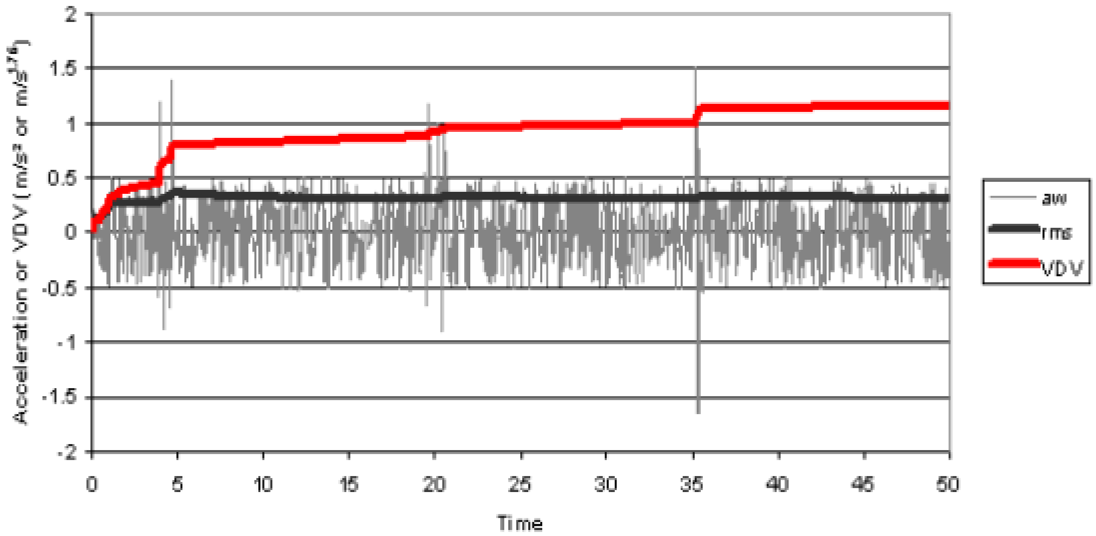


Figure 2

The Difference between **a_w(8)** and VDV

4.3.2 Information may be obtained either by the manufacturer of the equipment providing it, by seeking it from a database, or by measuring it. These three ways are discussed below.

4.3.3 Manufacturer-supplied information.
The supply of this information is a statutory requirement under the European Machinery directive for equipment supplied for use within the European Union from 1992 and should be provided as part of the equipment's instruction manual.

4.3.4 Manufacturers are often reluctant to declare such information for fear that it could be commercially damaging. This stance is somewhat justified as apart from that for lift trucks, there are few accepted standard methods for measuring the vibration to which equipment operators are exposed. Such measurements would require common factors, such as speed, loading, working surface conditions and a common repeatable work cycle to be applied, in order that like for like comparisons be made.

4.3.5 It is prudent therefore, when purchasing equipment, to request not only that the likely vibration exposure levels be provided but also that information be included detailing:-

- How the measurements were obtained and analysed,;
- A description of the test route used including, surfaces and conditions;
- The operating speed at the time of the tests;
- The driver's physical stature;
- His/her driving technique;
- The equipment's loading;

- The instrumentation used

in order to relate the vibration values to the specific conditions that the equipment will ultimately be working in.

4.3.6 Assessments carried out using manufacturer-supplied data will at best be a subjective estimate as the effect of local condition on the vibration levels declared will be the personal view of the assessor.

4.4 Databases

4.4.1 Similarly care needs to taken when assessing the risk using data obtained from databases. With the advent of the European directive, databases are being developed which, although containing data collected during actual operations of the equipment, frequently have no reference to the specific condition for each case. The data is often described as the Effective RMS Value sometimes for the three separate orthogonal axes, which does require interpretation and often omits information on peaks, VDVs or crest factors (See 4.2).

4.4.2 It is also unclear whether the values given have had the “k” factor (see 4.5.6) applied or not.

4.4.3 Enquiries revealed that the data in the European vibration database set up by the National Institute for Working Life in Sweden does not have “k” factors applied to either individual axis acceleration values or the vector sum values, which is misleading when assessing risk.

4.5 Measurement

4.5.1 The most effective way of obtaining the vibration level to which operators are exposed must be that of measuring it under normal working conditions in the actual environment in which it is to be used whilst being operated by the normal operators. Variables will still exist such as driver weight and techniques but if measured over a reasonably typical work cycle these will be minimised.

4.6 Measurement Methodology

4.6.1 The methods of measuring and interpreting the vibration levels to which equipment operators are exposed is detailed in ISO 2631 –1 1997. Measurements are basically carried out using an accelerometer placed at the interface between the operator and his seat in the case of a seated operator, or his feet and the floor in the case of a standing operator (Figure 3). For the seated person the accelerometer should be placed on the seat directly below the ischial tuberosities. In each case the vibration should be measured in each of the three orthogonal axes as shown in the diagram.

4.6.2 The standard notation is that

x = the vibrations acting horizontally in the fore and aft direction
y = the vibrations acting horizontally in the side to side direction
z = the vibration acting vertically

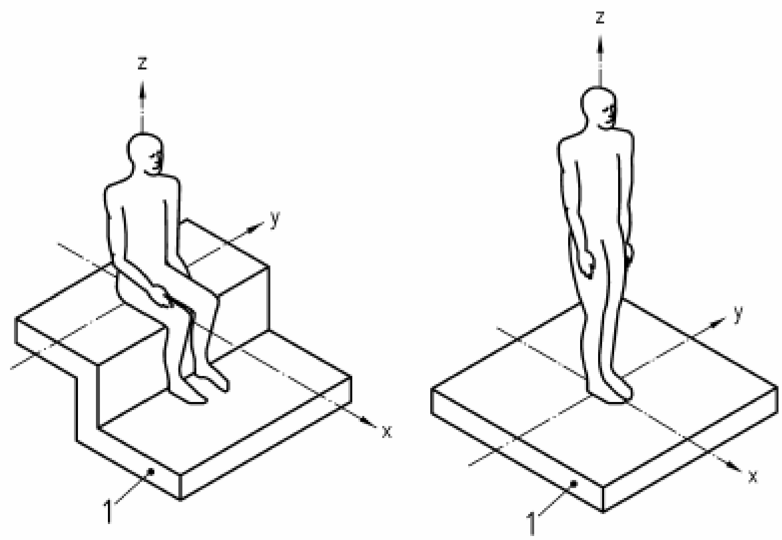


Figure 3 - Measurement position and designation of axes

4.6.3 Ideally the measurement in the three axes should be made simultaneously. This can be done using a tri-axial accelerometer imbedded in a rubber pad (Figure 4). An example of the standard version of such an accelerometer is shown in the picture below. A suitable design for such an accelerometer can be found in ISO 10326-1 Figure 2.

4.6.4 The duration of the measurement should be such that the average vibration is recorded during a period representative of the typical operation of the equipment. Where the operation is cyclic, a duration of at least one operating cycle, but preferably more should be used. Experience has showed that a period of 30 minutes is adequate in most cases.

4.6.5 The instrumentation used should be capable of applying the Wk and Wd frequency weightings as defined in Table 3 of ISO 2631-1 (see also figure 1). The Wk weighting should be applied to the z axis measurement and the Wd to both the x and y axes.

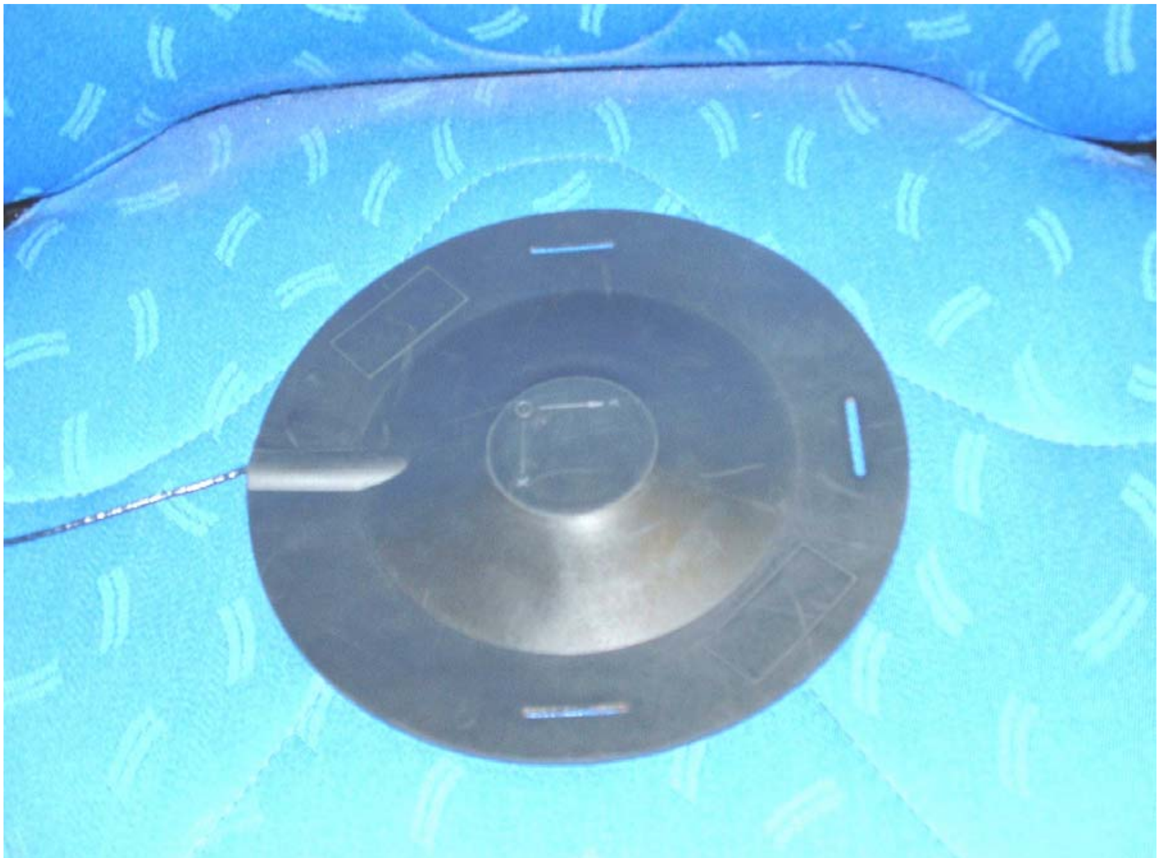
1 

Figure 4 - A typical tri-axial accelerometer to the requirements of ISO 10326-1

4.6.6 Having obtained the average frequency weighted RMS acceleration (aw) for each of the three axes a further factor must be applied for seated operators. The resulting a_w 's must be multiplied by a factor "k" which represents the differing effects which vibration in each of the orthogonal axes on the human body.

k = 1.4 for the x and y axes

k = 1.0 for the z axis

4.6.7 The resulting measurements should then be compared and the highest of the three axes used as the effective aw for assessing the risk. ie the calculation of the effective a_w8 (see section 4.1 Risk Assessment)

4.7 Health Surveillance

4.7.1 What is health surveillance?

4.7.1.1 Health surveillance is the collection and analysis of data pertaining to the health of a person or a group of people for the purpose of preventing injury or ill health. In the case of WBV and this study, the data pertaining to back pain may be used to identify whether a problem exists or not because of exposure to vibration, how big or significant the problem is and whether the problem is improving or deteriorating.

4.7.1.2 Its purpose should not merely be to detect and prevent permanent disabling injury but to preserve and where possible improve the quality of life of the employees.

4.7.1.3 Health surveillance should, where possible, be carried out by an independent professional, and it should always maintain confidentiality and the individual's privacy. It should commence in the pre-employment process in order to collect baseline data and then at regular intervals in order to detect trends.

4.7.1.4 As the main health problem associated with WBV is the onset or exacerbation of LBP. Bearing in mind that LBP itself can have multiple causes, including the ergonomic problems associated with vehicle drivers and, in particular, crane operators, it is probable that no clear indication of the effect of WBV can be detected from the results. It is therefore prudent to carry out a cost-benefit analysis considering the degree of risk that exists from the vehicles and plant in use and the cost of the surveillance. The outcome will be a programme that is proportional to the risk and is likely to be part of an overall medical assessment and health surveillance programme which is required in order to ensure that port workers have and maintain "a good physical constitution". (ILO 2005). If from the data collected trends or hotspots emerge then the programme can be upgraded or modified to focus on these areas.

4.7.1.5 The main element of such surveillance will be in the form of a questionnaire collecting relevant information. Where it is discovered that back pain has been experienced within the previous twelve months a physical examination should be carried out by a medical practitioner.

4.7.2 Who will require Health Surveillance?

4.7.2.1 The European Physical Agents (Vibration) Directive requires that health surveillance be put in place where employees are exposed to levels of WBV averaged over a working day (a_w8) of 0.6 m/s^2 and above. This action level will cover most drivers of vehicles and operators of plant apart from the drivers of automobiles on well maintained roads, quay crane and RTG. The latter two however will probably require similar surveillance because of the posture which they need to adopt while driving.

5 MINIMISING THE RISK

5.1 Engineering Controls

5.1.1 Elimination at Source

5.1.1.1 The first consideration as with all workplace stressors, must be that of eliminating the stressor at source.

5.1.1.2 The major source of vibration within the port industry is that of wheeled plant and vehicles moving over surfaces or on rails therefore it is important to design, construct and maintain roadways, rails and working surfaces which are as flat, smooth, hump and pothole free as is reasonably practicable. Crane rails and rails on which hoist trolleys run, being mostly steel to steel contact require particular care in their design, construction and maintenance especially in the areas of rail and boom joints. Here the choice of material plays an important part so that wear occurs in the wheels which are easier to replace and maintain than the rails on which they run.

5.1.1.3 Another source of vibrations is that of shocks from loads being handled such as, loads being lowered heavily onto trailers, the load-swing which occurs when loads are lifted without crane hoist ropes being perfectly vertical, or the sudden release of jammed loads when the crane takes the strain. Control at source for these instances is not possible although the grounding of trailer legs and general training of plant operators can keep occurrences to the minimum.

5.1.1.4 The third source is that of vibration from the prime-movers and transmission systems. Of these diesel engines is a major source. Here maintenance is a key factor for reduction at source. The vibrations tend to be at higher frequencies to those transmitted from the movement of the plant or vehicle, and therefore are easier to attenuate using rubber mountings, suspension seats and even the foam pad on the seat itself.

5.1.2 Isolation

5.1.2.1 There will however inevitably be situations that will result in vibration at the operators' workplace, such as inherent surface defects (drains, manholes, boom joints, crane and railway tracks, etc) as well as the mishandling of loads and, of course, general wear and tear. It is therefore prudent for other controls to be in place. The principle is to isolate workers exposed to vibration from its source.

5.1.2.2 In most vehicular type plant there are four points where these isolations can be inserted. Each of which has its own important considerations as well as a requirement to complement each other, although this is often not the case. The main possibilities for isolation are, the type of tyre fitted to wheels, the vehicle overall suspension, the cab suspension and the seat itself.

5.1.2.3 A degree of isolation is possible by inserting a strip of rubber or similar resilient material beneath the rails and the plant structure. This will have the effect of isolating higher frequencies but at lower frequencies its effect will be minimal

5.1.3 Tyres

5.1.3.1 Pneumatic tyres will, if inflated to the correct pressure for the equipment and task, filter out small irregularities in the surface but are normally chosen for properties other than their ability to absorb vibration such as grip, ability to support loads, resistance to damage and, of course, cost. Pneumatic tyres do not have the damping and stiffness qualities necessary to absorb vibration to any extent and often allow vibration to build up even on flat surfaces. Tyres effective at isolating vibration would require 10 times their normal absorption qualities - which would mean larger, softer, tyres in which a build-up of heat would be a major problem.

5.1.3.2 Because of their inherent stiffness the isolation effect of solid tyres is minimal. Future development may lead to fillings for these tyres that improve the necessary qualities. (Donati, P. 2002)

5.1.4 Vehicle Suspension

5.1.4.1 Many items of plant of course do not have an option to fit pneumatic tyres. Some items run on installed steel tracks while others lay their own tracks.

5.1.4.2 Much port plant has little or no suspension between wheels and chassis possibly either because of the sizes that would be involved to support the weights being handled or the cost involved. Many terminal tractors are fitted with leaf spring suspension (Figure 5) with dampers on the front wheels, but none on the rear, possibly because of the weight of the loads they are intended to bear, and presumably the size and cost involved. Some tractors are fitted with token pneumatic rear suspension systems (Figure 6) which provide isolation when the trailers are lightly loaded (ie loads below 7-10 tonnes on the king pin), but bottom out when greater loads are imposed. This can have an adverse effect causing shocks during towing when trailers are loaded at or just below these values. (Donati, P. 2002)

Figure 5 - Front suspension on a typical container terminal tractor (tug) combining rubber buffer leaf spring and hydraulic damper

5.1.5 Cab Suspension

5.1.5.1 The third position at which isolation can be inserted is between the chassis and the cab structure. Often on port plant this isolation is in the stiff rubber mounts (Figure 7) or coil springs with rubber buffers and sometimes hydraulic dampers.

Figure 6 - Rear suspension on a typical container terminal tractor (tug) combining rubber pneumatic suspension (airbag) and hydraulic damper

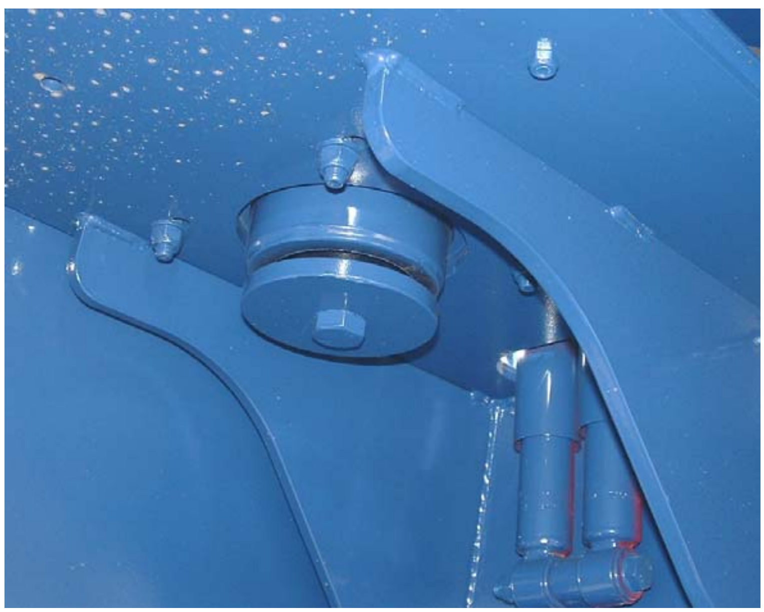


Figure 7 - Rubber block cab suspension with twin dampers

5.1.5.2 The development of full (active) suspension cabs for the agricultural and road haulage industries makes economical systems available that can be incorporated into port plant.

5.1.5.3 Such systems have the front of the cab mounted with rubber-lined pivots with pneumatic suspension units at the rear. If these are designed with low natural frequencies, well below the inherent frequencies that are transmitted to the chassis, they can be very effective in isolating the vibrations, giving up to 50% reduction. (Donati, P. 2002)

5.1.6 Seats

5.1.6.1 The final position at which isolation can be inserted is between the cab floor and the operator: that is to incorporate it in the seat itself. In some plant this is the only point at which suspension or vibration isolation is used. The seat is therefore an important element of controlling vibration and worthy of more consideration than is often given

5.1.6.2 Seats, if wrongly chosen, can often amplify the vibration rather than attenuate it. Suspension seats (Figures 5.4 and 5.5) will only attenuate vibration of a higher frequency than their attenuation frequency (f_a). (Donati, P. 2002) The attenuation frequency is the natural resonant frequency (f_r) multiplied by √2 ie $f_a = f_r \sqrt{2}$ which in practice often approximates 2 x √2 = 2.8 Hz

5.1.6.3 The source frequencies experienced from the motion of port vehicles, and indeed the natural frequencies of other suspension elements, are often no higher than this figure, resulting in seats amplifying the vibration (a common occurrence experienced by the author).

The problem with designing seats with a lower natural frequency is the fact that the distance of suspension travel required to effect isolation increases as the frequency decreases, needing some 150mm at 1.5 Hz. (P. Donati 2002). This presents the problem of the operator maintaining satisfactory contact with the plant controls. In these cases the answer may well be the insertion of cab suspension omitting the suspension on the seat.

5.1.6.4 Most seats are designed assuming that the effective vibration will be in the vertical (z) axis. This is not always the case. Vibration in the fore and aft (x–axis) is often experienced due to the movement at the interface of a tractor unit and its trailer or on container cranes, where the trolley is winched forward and backwards via lengths of rope from the machinery house and slack is taken before the initial movement takes place.

5.1.6.5 There are seats on the market with additional spring and damper mechanism which operates in the horizontal planes as well as the more common vertical mechanisms, giving a degree of isolation to minimise vibration acting in these directions.

5.1.6.6 With suspension seats it is also important for the operator to adjust the suspension stiffness for his own personal weight. An adjustment with a calibrated dial is often provided. Air suspension seats are more likely to have automatic adjustment so that the need for operator adjustment is eliminated.

Figure 8 A typical air suspension seat fitted in a terminal tractor

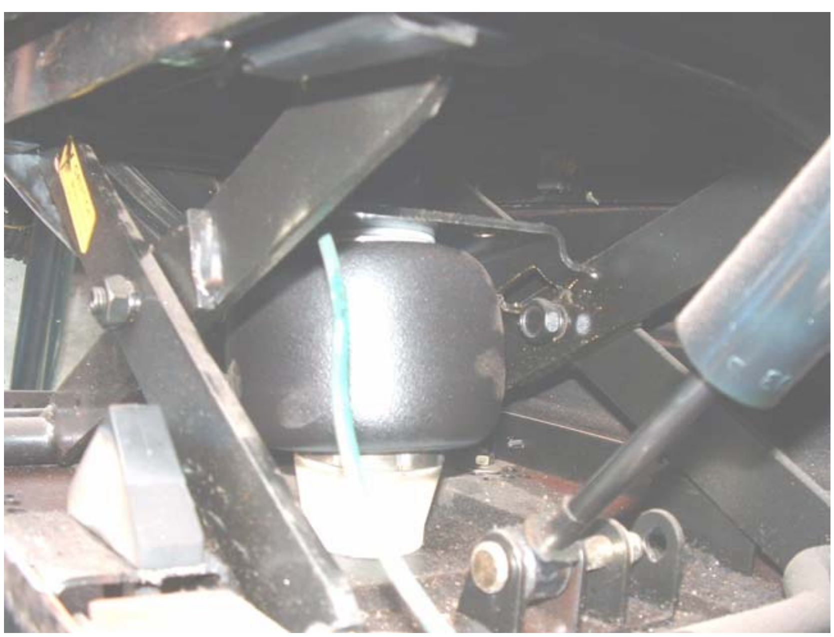


Figure 9 - A suspension seat showing the air suspension unit damper and scissor mechanism

5.1.6.7 Maintenance of the seat is no less important than the maintenance of any other part of the plant or vehicles. Even a badly worn seat pad can result in a poor posture being adopted by the operator, which increases the risks of lower back pain and the adverse effect of the vibration.

5.1.7 General Considerations of engineering controls

5.1.7.1 It can be seen from the above that although different parts of plant can be used to isolate the operator from the source of vibration, none will be fully effective unless their design is considered in combination with each other, and their maintenance is given the same importance as other parts of the machinery which are often the only parts maintained due to their direct effect on productivity.

5.1.7.2 There is also a need for manufacturers to carry out further research and develop plant and vehicles in which the vibration to which the operator is exposed is reduced to levels that do not present a health risk.

5.2 Management Controls

5.2.1 In section 3.1 the important fact that the risk from exposure to vibration is dependent on the duration of the exposure as well as the vibration magnitude is discussed and the $a_w(8)$ value described.

5.2.2 Management can control the exposure of the workforce by adopting a policy to purchase plant and equipment that minimise the vibration exposure of the driver. Such equipment may well be difficult to choose, as apart from lift trucks, standard methods for evaluating vibration have yet to be developed. Vibration levels in practice will depend on the operating environment (surfaces etc) and the speed of operation, therefore making comparisons may be difficult. Manufacturers are often reluctant to disclose the expected vibration levels at operator stations in fear of jeopardising sales in spite of, in Europe at least, being required so to do.

5.2.3 It is prudent to require the equipment manufacturer to provide information in his tender documentation on the likely vibration levels to which operators will be exposed. Buyers should also request information as to how this value has been arrived at or measured, and under what conditions; and what instrumentation was used to make the measurement. This will assist in making comparisons between equipment and will also allow checks to be made to verify the manufacturer's claims.

5.2.4 The level of the vibration can be reduced by limiting the speed at which plant operates, either by governing it mechanically or by simply introducing and enforcing speed limits.

5.2.5 An important element in reducing the risk is that of controlling the duration of a person's exposure to the vibration. This can be achieved by adopting appropriate shift patterns, by building rest breaks into the shift pattern or by rotating the workforce so that the exposure to the machinery with the highest vibration magnitude is shared and balanced with durations of exposure to machines, or work routines, with lesser vibration risks. The objective should be to reduce the individual's daily exposure in terms of the $aw_{(8)}$ as low as is reasonably practicable and at least, if we use the limit value from the European directive as target, to 1.15 m/s^2 (or if the VDV is being used, to 21$m/s^{1.75}$).

5.3 Future Development

5.3.1 There is scope for improvement and the reduction in levels of whole body vibration experienced by the operators, within the design and manufacture of port plant and equipment which will not involve the sacrifice of efficiency or involve the managing and control of a worker exposure time.

5.3.2 These improvements will not be forthcoming unless pressure is put upon the manufacturers by the purchasers to undertake the necessary design and development. This pressure can be applied by demanding the highest standards and accurate meaningful information prior to and when taking delivery of new machinery.

5.3.3 Project, Engineering and Purchasing departments need to consult, and work together with Health and Safety professionals so that appropriate specification for new plant can be developed.

5.3.4 It is obvious that because the natural frequencies of seats, suspensions and human spine itself are all in a similar spectrum (1.5 – 7 Hz) and the distance of suspension travel required to isolate the operator at these low frequencies is high, the improvement must come from other than that of fitting a suspension seat, as is the case at present. Further investigation must centre upon the combined effect of more than one isolating element, for instance, a suspended cab together with a seat. The investigation into the effect of vibration isolation elements operating in series is beyond the scope of this study but one that is used in other scenarios and one that needs to be adopted when designing port plant.

5.3.5 The provision of a realistic data base for typical vibration levels for various items of port plant needs to be developed as a tool for assessing WBV risks within the port industry.

6 CONCLUSION

6.1.1 Low back pain is one of the world's most common health problems. Although WBV is just one possible causal or exacerbation stressor of the symptom (albeit with an unclear exposure/response relationship), minimising the risks which it presents to the drivers of port plant is both economically and socially prudent. It is a step in the right direction towards reducing the amount of revenue lost and the suffering caused by back pain and towards increased efficiency by reducing operators' discomfort while working.

6.1.2 A good management strategy is therefore required to control these risks. This strategy will include :

- Making sufficient assessment of the risks from WBV by ascertaining the probable vibration magnitude for each item of plant used and the length of time for which each employee is exposed to that vibration.
- Taking the necessary steps to reduce the exposure to vibration to levels as low as is reasonably practicable, (at least to below an A8 of 1.15 m/s^2).
- Monitoring the health of employees so that problem areas can be identified and where possible improved and deterioration in health monitored and where necessary halted.

- Purchasing plant and equipment that exposes employees to the lowest levels of WBV; encouraging suppliers and manufacturers to provide accurate information; and to include WBV together with good ergonomic principles as a significant element of the design criteria and purchase specification.

- Developing collaboration between purchasing functions, engineering functions and health & safety professionals so that refits and upgrades meet the standards set for new equipment.

- Maintaining plant and equipment, including the oft-forgotten suspension and seating, to a high standard.

- Maintaining roads, rails and working surfaces to provide level, continuous working areas that are free of potholes and similar defects likely to create shocks.

- Providing training and information to employees about the levels to which they are exposed, the likely risks to their health and methods by which they reduce that risk to a minimum.

APPENDIX 1

Port Machinery Vibration Data

Vehicle / Equipment Type	**Information Source**	**Average Acceleration A_w M/S^2**	**Acceleration Span A_w M/S^2**
Small car	UK Health and Safety Executive	0.4	0.2 – 0.5
Articulated lorry	UK Health and Safety Executive	0.7	0.4 – 1.0
Straddle carrier	UK Health and Safety Executive	0.7	0.4 – 1.0
Straddle carrier	European Vibration Data Base	0.42	
Ro-ro tractor - pontoon type bridge	Measured by author	1.29	1.08 – 1.5
Ro-ro tractor - single span bridge	Measured by author	0.79	0.57 –– 0.95
Quayside container gantry cranes	Measured by author	0.23	0.15 – 0.33
Quayside container gantry cranes	European Vibration Data Base	0.2	
Quayside slewing (jib) cranes	European Vibration Data Base	1.46	1.12 – 1.83
Empty container handling lift trucks	Measured by author	1.37	1.14 – 1.74
Shovel loaders	European Vibration Data Base	0.76	0.5 – 1.3

APPENDIX 2

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APPENDIX 3

Symbols and Terms

a_w	The frequency weighted RMS acceleration
$a_w(8)$	Vibrations exposure expressed as the frequency weighted RMS acceleration averaged over an 8 Hour working day.
VDV	Vibration Dose Value – Vibration exposure expressed as the frequency weighted fourth power acceleration.
Terminal or container tractors	A tractor unit for towing fifth wheel trailers and mafis often used for transporting containers. Sometimes referred to as tugs, IMV, or haulage units
Accelerometer	A transducer for transforming mechanical vibration into an analogue electrical signal.
Ro-Ro terminal tractor	A tractor unit for towing fifth wheel trailers and mafis used for loading roll on- roll off vessels. Sometimes referred to as tugs, IMV, or haulage units
WBV	Whole Body Vibration
LBP	Low Back Pain
Clamp trucks	Lift trucks equipped with a clamp device for lifting reel of paper or bales
Bobcats	Small mechanical shovels
Boom Joints	The connection point for trolley rails and the hinge point of a quayside gantry crane
RMS	Root Mean Square – A common method of determining an average of a varying parameter in which the negative deviations do not cancel out the positive deviations, in order that total energy is considered. It is used in the case of vibration so that an acceleration measurement is proportional to the vibration energy.
ISO	International Standards Organisation
Hz	Cycle per Second - Frequency
x axis	Horizontal Fore and Aft axis
y axis	Horizontal Side to side (left to right) axis
z axis	Vertical (up and down) axis
f ; f_r ; f_a	Frequency ; Natural Resonant Frequency ; Attenuation Frequency