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Investigation on Whole Body Vibration exposures of operators of construction vehicles

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Abstract: There is a growing interest in the areas of increased comfort and reduced vibration exposure levels in construction vehicles. It is necessary to understand the level of Whole-Body-Vibration (WBV) exposure since it affects comfort and health performance of humans. Objective of this study is to investigate the exposure levels in operators of construction vehicles. In addition, preventive strategies, which are needed to reduce low back pain problems due to WBV, will be investigated.

Ten operators of vehicles were selected where the vehicles were chosen so that those are vastly used in the construction sector. In this study, it was selected three construction vehicle types: excavators, backhoes and roller vibrators. A questionnaire survey was carried out with each operator regarding their profession, age, working experiences, health and exposure duration. The vibration exposure levels induced on operators bodies were measured using a tri axial vibration meter (SV 106) attached to a seat pad accelerometer. The operator was instructed to sat on seat-pad accelerometer and WBV exposures in three directions (i.e., vertical, fore-and-aft and lateral) were measured. It was found that the vibrational effect on vertical direction is more dominant than the other two directions (i.e., lateral and fore-and-aft). Measured vibration exposure levels were assessed based on recommendations given in ISO 2631:1997 and are presented in the paper.

Keywords: Excavators, backhoes, roller vibrator, Seat pad accelometer, Occupational health, ISO 2631-1 and EU directive 2002/44/EC

1. Introduction

In Sri Lanka, workers employed in construction sectors are frequently exposed to vibration within their career (Vitharana et al, [1]). Operators of construction vehicles are exposed to Whole body vibration (WBV) while in standing posture but more often in seating postures (Subashi et al, [2]). Human body at seated posture shows resonance at about 5 Hz in vertical vibration and about 1-3 Hz horizontal vibration, and attributed by in significant motion of several parts of the human body (Subashi et al, [3]). This indicates that vibration can cause long-term painful damage. Shocks and jolts from driving certain types of vehicles can cause severe back pains. However, workers, are not much aware on risk associated with occupation vibration exposures (Vitharana et al, [4])

Exposure to high levels of WBV can increase risks to health. When the vibration magnitudes are high, the damage can be severe and naturally irreversible. In addition to the magnitude, exposure durations, frequent, resting duration, and the vibration consisting with severe shocks or jolts are the major considerations when studying the risk

Associated with vibration exposure (Griffin, et al. [5]).

Continuous exposure to WBV is one of the leading risk factors for the development of low back disorders. WBV can also humble other systems in the body suppressing the operation of the musculoskeletal, cardiopulmonary, metabolic, cardiovascular and gastrointestinal systems (Blood, et al. [6]). Comfort levels of the operators highly depend on the amount of vibration induced as well as long term effects. Unexpected shocks or jolts can also be affected on the operators' concentration and that could be caused on occurring accidents.

Most commonly used orthogonal axis system for the whole-body vibration investigation is, the foreand-aft direction is defined as the x-axis, vertical direction as the z-axis and lateral direction which is perpendicular to above both axis as the y-axis, rotation around the x-axis called as roll, rotation around the y-axis is called as pitch and rotation around the z-axis is called as yaw (Mansfield, [7], ISO 2631-1 [8]). For the quantitative analysis of the vibration exposure levels, it was required well defined parameters that could be easily measured. In that case Maryanne, [9] suggested f e w

evaluating parameters and among them Root mean square value (RMS) and Vibration dose value (VDV) are ideal for analysing exposure levels with more variations.

Large construction activities in Sri Lanka have been increased during the recent past few years. Hence the site workers have to use new technology as well as new machineries whenever they are engaging with the construction activities. Most probably the vibration is used as an energy conveyer which is useful while doing some specific works such as breaking, drilling and compacting etc. Also vibration is induced due to moving of heavy vehicles and equipment. However the employees may not be aware about the health effects associated with long-term exposure to vibration. As a result, vibration related injuries are neglected in Sri Lanka.

Objective of the present study is to investigate whole body vibration exposure levels of operators of excavators, backhoes and roller vibrators in construction industry.

2. Methodology

Sequence of the study is described with study group, questionnaire survey, instrument that was used to measure exposure levels, measuring procedure of exposure levels and analysis.

2.1. Study group

Ten construction operators were selected as the study group, which consists of three excavator operators, three backhoe operators and four vibrating roller operators. Before conducting the questionnaire survey and measurements, each operator was informed about the questionnaire survey and measuring procedure of exposure levels and what they should be done. Age range of the operators participated in the current study was 20-50 years.

2.2. Questionnaire survey

Prior to the site visits, questionnaire survey forms were prepared according to the instructions published in a previous study (Griffin, et al. [5]). The survey was conducted for each operator to investigate their health levels and current situation of their profession. In addition, their work experience and age were recorded. Questions were asked from each operator by the experimenter and the survey forms were completed.

2.3. Instrument

For investigation of vibration exposure levels that transmitted to operator's body, a tri- axial accelerometer was used (Figure 1). The tri axial accelerometer, SVANTEK 106, is a small size instrument and it is very easy to use at construction sites. The SV 106, which is a six-channel human vibration meter and analyser, was used to analyse the vibration exposure levels found in three different directions: vertical, for-and-aft and lateral.

2.4. Measuring exposure levels

Measurements were taken, while operators were engaged in their daily works in the period between 9.00 am to 4.00 pm.

Basic instrumental setup including selection of suitable parameters was installed to the SV 106 before taking any measurement. In order to have a desired measurements from the instrument, start delay time, measurement duration, weighting factors for each axis and repeat duration were initially set under instrumental setup. The measurement duration was decided such a way that at least one typical working cycle should be included in the measurements while minimizing the disturbance of the operators' duty as much as possible.

The sensor of seat pad accelerometer was properly placed on the driver seat as shown in Figure: 1-(a). Three axes indicated on the seat pad should be coincided with the one specified (Figure 1-(b)).



Figure 1: Seat pad sensor was placed (a) Seat pad sensor was placed on the

(b) Specified axes of vibration

seat

After placing the sensor, operator was instructed to seat on the sensor carefully and operate the vehicle as usual (Figure: 2-a). Measurements were recorded during the operation as shown in the Figure: 2-b.



(a)

Figure 2: Measuring WBV exposure

(a) Operator was instructed to seat on the sensor

(b)

(b) Recording measurement

2.5 Analysis

For each direction, measured vibration with weighting filter, *aw*, was obtained from SV 106 analyser. Vector sum of frequency weighted rms accelerations (or vibration total values), *av*, were obtained from Equation 1 (ISO 2631-1 [8]).

$$av = \sqrt{(1.4 * aw_x)^2 + (1.4 * aw_y)^2 + aw_z^2} \quad (1)$$

Where a_{wx} , a_{wy} and a_{wz} are the frequency weighted rms acceleration in x, y, z orthogonal axes respectively

For each direction, daily vibration exposure of 8 hrs equivalent frequency weighted rms acceleration value was determined by using Equations 2, 3 and 4 ((Griffin, et al. [5]).

$$A_{\chi}(8) = 1.4 * a w_{\chi} \sqrt{\frac{T_{EXP}}{T_0}}$$
 (2)

$$A_Y(8) = 1.4^* a w_Y \sqrt{\frac{T_{EXP}}{T_0}}$$
 (3)

$$A_Z(8) = a w_Z \sqrt{\frac{T_{EXP}}{T_0}}$$
(4)

Here, T_{EXP} is the duration of exposure to the vibration and T0 is the reference duration of eight weighting filter) variation of backhoe operator (OP6) for vertical, fore-and-aft and lateral hours. The highest value of $A_x(8)$, $A_y(8)$ and $A_z(8)$ is considered as the daily vibration exposure, and was compared with exposure limits.

Summary of limits associated with different levels of predicted health risk according to the "Health Guidance Caution Zone (HGCZ)" values discussed in ISO 2631-1are given in Table 1.

Table 1: Health risks categorized according to
ISO2631-1 with A (8)

ISO 2631-1assessment of adverse health effect	A(8) (ms ⁻² r.m.s)
Below the zone (HGCZ) no health effects observed	<0.45
In the zone (HGCZ) Caution with respect to potential health risks is indicated.	0.45-0.90
Above the zone (HGCZ) health risks are likely.	>0.90

3. Results and Discussion

3.1 Questionnaire survey

Age, experience, exposure duration and health issue of all operators are summarised in Table 2. It seems that age and past experience (number of

years exposing to whole body vibration) are the most critical factors that could be affected on the operators' health relative to the others. Among vibrating roller operators, OP1, who has one year experience and age is 23 years does not feel any health issues in his career as an operator. All three backhoe operates were affected by the vibration (Table 2) perhaps, attributed by long term WBV exposures (i.e., experience of those operators relatively greater)(Table 2). Excavator operator, OP10, has not been affected by any difficulty as well. He is also a relatively young operator with two year experience. Operators, who have been exposed to WBV in several years with fairly older age have been suffered with health issues: 50% of operators have back pain and 30% of operators nave Normal daily tiredness.

3.2. Vibration exposure levels

Figure 3 shows a_w (measured vibration with directions. It can be seen that operator was exposed to number of shocks, although they are not in large magnitude.

Frequency weighted rms value, a_w , for vertical direction is 0.45 ms⁻². However, for the fore – and-aft direction and lateral direction, it was 0.28 ms⁻² and 0.3 ms⁻², respectively, which are lesser than the a_w value found for the vertical direction.

 Table 2: Age, work experience, exposure duration and health issue of ten operators

Equipment	Operator	Age (vear)	Work Experience (years)	Exposure Duration (hours)	Health Issue (regarding operation)
	OP 1	23	1	6	No
Vibrating roller	OP 2	31	8	6	Back Pain
	OP 3	32	5	5	Normal daily tiredness
	OP 4	36	9	6	Back Pain
	OP 5	37	10	5	Back Pain
Backhoes	OP 6	32	10	5	Normal daily tiredness
	OP 7	37	12	5	Normal daily tiredness
Excavator	OP 8	30	6	4	Back Pain
	OP 9	35	15	3	Back Pain
	OP 10	23	2	6	No

Table 3: Range of Frequency weighted rms acceleration a_w in three orthogonal directions

	Range of a_W values (ms ⁻²)				
Operator	Fore and aft direction	Lateral direction	Vertical direction		
Vibrating Roller	0.07-0.21	0.07-0.21	0.44-1.42		
Backhoe	0.19-0.59	0.22-0.36	0.29-0.74		
Excavator	0.13-0.37	0.09-0.47	0.07-0.94		

Range of frequency weighted rms acceleration, a_w , for each type of vehicle is summarized in Table 3. It can be observed that the vibrational effect on vertical direction is more dominant than the other two directions (i.e., lateral and fore and aft). Vibration total value, a_v , variation with the time of vibration obtained from the same operator (OP6) is shown in Figure 4. Average of this variation is 0.83ms^{-2} .



Figure 4: Vibration total value, av variation against to the time for the backhoe operator, OP6



Figure 3: $a_{\rm w}$ variation for the backhoe, Operator 6,

Equipment	Operator	Exposure Duration (hours)	Vector sum of frequency weighted r.m.s accelerations	Daily exposure A(8) ms ⁻²	Health Risk according ISO 2631-1
	OP 1	6	0.83	0.56	In the zone
20	OP 2	6	0.90	0.65	In the zone
Vibratin Roller	OP 3	5	0.49	0.35	Below the zone
	OP 4	6	1.42	1.23	Above the zone
oes	OP 5	5	0.51	0.28	Below the zone
Backh	OP 6	5	0.83	0.43	Below the zone
	OP 7	5	1.15	0.65	In the zone
xcavat Or	OP 8	4	0.24	0.11	Below the zone
	OP 9	3	1.28	0.66	In the zone
Щ	OP10	6	0.91	0.47	In the zone

Table 4: Assessment of WBV based on ISO 2631-1(1997)

Vector sum of frequency weighted r.m.s accelerations values of each operator have characteristics which are related to the daily exposure value. Many of the operators are exposed to daily vibration exposure within or above the Health Guidance Caution Zone (HGCZ) (Table 4). One of vibrating roller operator, OP4, is exposed to daily vibration exposure above HGCZ and is in high danger than the other operators. Vibrating roller operator, OP 3, backhoe operators, OP 5, OP6 and excavator operator, OP 8 are exposed to daily exposure, which lies below the caution zone. As mentioned in the ISO 2631-1 health risks on those operators may not be much concerned. Rest of the operators are exposed to daily exposures in the caution zone and there are possible potential to effect on the health levels of those operators. This indicates that an appropriate formalised preventive programme must be set up by the employer to reduce to a minimum the exposure to vibration and attendant risks.

5. Conclusions

It seems that age and past experience (number of years exposing to whole body vibration) are the most critical factors that could be affected on the operators' health in addition to the daily vibration

exposure, which could be determined from Whole body vibration measurements

Vibration total value or Vector sum of frequency weighted r.m.s accelerations values of each operator has characteristics which are related to the daily exposure value. According to the ISO 2631:1997, vibrating roller operators have higher potential of facing health effect than other two category discussed in this study. Majority of operators in the study groups are in Health Guidance Caution Zone (HGCZ).

When compare the vibration exposure levels of three axis (i.e. fore and aft, lateral and vertical), it was identified that highest average value always taken by the vertical axis than other two for each three category of vehicles. Therefore to minimize the health risk on the operators, it is desired to damp the vibration that comes in vertical direction.

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