WHOLE-BODY VIBRATION EXPOSURE OF HEAVY EARTH MOVING MACHINE OPERATORS IN SURFACE MINES: A MAJOR HEALTH CONCERN

Ashis Bhattacherjee
Professor

DEPARTMENT OF MINING ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY
KHARAGPUR, INDIA

INTRODUCTION

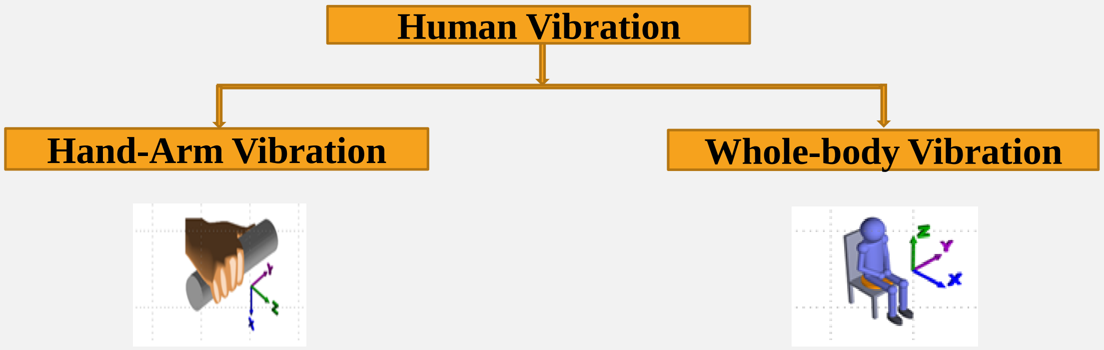
- The **US department of Labour** classified mining as one of the most hazardous occupations in terms of ergonomic exposures (incidence rate of WMSDs is **30** per **10,000** workers).

- Human exposure to vibration (human vibration) is classified as one of the physical occupational hazard in the workplace.

- Human vibration is separated in to two sub categories:

- **Hand-Arm vibration (HAV)** associated with the use of vibrating hand tools.

- **Whole-body vibration (WBV)** associated with HEMM operators such as dumpers, dozers, graders, and rollers.



- Long-term exposure to whole-body vibration of HEMM operators is associated with various health issues. However, there is a lack of information about these in mines.

HEALTH RISKS: WHOLE-BODY VIBRATION

- **Lower-back pain, spinal degeneration, neck problems** (NIOSH 1998)

- **Muscle fatigue**

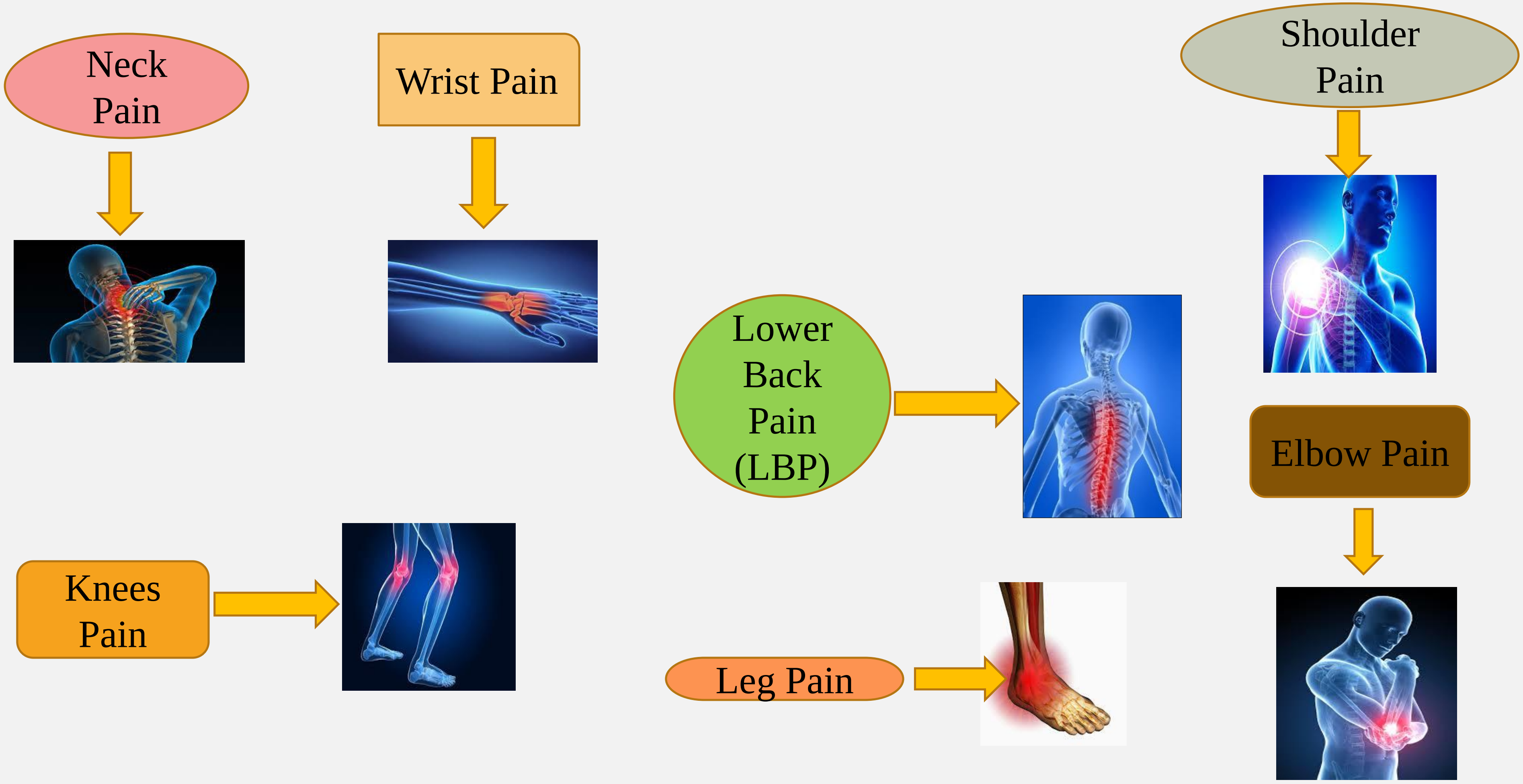
- **Sleep problems, headaches, & nausea**

- **Hearing loss**

- **Gastro-intestinal tract problems**

(Scutter et al., 1997; Seidel, 1993; Seidel, 2005; Thalheimer, 1996; Mansfield, 2005)

MUSCULOSKELETAL DISORDERS PROBLEMS FROM WBV TO HEMM OPERATORS IN MINES



Motivation

- Exposure to Whole-body vibration is an emerging issue for the mining industry and inherent to many mining operations.

- These vibrations are caused by accelerations produced by HEMMs during its operation and are transmitted to the machine operators through the seat or the feet.

- High levels of exposure can lead to health risks, which are more important when the vibration magnitudes are high, the exposure duration is long, frequent, and regular, and when the vibration includes frequent shocks or impacts.

- In the **11th National Conference of Safety in mines**, held in **New Delhi, 2013**, DGMS has recommended that vibration studies and the ergonomic assessment of various mining machines should be conducted prior to their introduction into mining.

WBV EXPOSURE OF MINING EQUIPMENT OPERATORS

Equipment Type	Application	Vibration Exposure		Vibration Exposure		Study Reference
		$A(8)$ m/s^2	Health Risk[1]	VDV_{total} m/s$^{1.75}$	Health Risk[2]	
Haul Truck (16 ton)	underground nickel mine	1.20	High	----	---	Eger et al., 2006
Haul Truck (30 ton)	open pit mine	0.69	Moderate	14.5	moderate	Smets et al., 2010
Haul Truck (36 ton)	open pit mine	0.78	Moderate	16.4	moderate	Smets et al., 2010
Haul Truck 50 ton	aggregate stone quarry	0.99	High	---	---	Mayton et al., 2008
Haul Truck 70 ton	aggregate stone quarry	0.58	Moderate	---	---	Mayton et al., 2008
Haul Truck (100 ton)	open pit mine	0.74	Moderate	12.4	moderate	Smets et al., 2010
Haul Truck (150 ton)	open pit mine	0.61	Moderate	10.8	moderate	Smets et al., 2010
Haul Truck (240 ton)	overburden mining	0.71	Moderate	---	---	Kumar, 2004
Haul Truck (320 ton)	overburden mining	0.67	Moderate	---	---	Kumar, 2004
Bulldozer	underground nickel mine	1.64	High	---	---	Eger et al., 2006
Bulldozer	surface coal mine	0.59	Moderate	11.8	moderate	Burgess-Limerick, 2012
Bulldozer	South African Mine	2.0	High	---	---	Van Niekerk et al., 2000
Grader	underground nickel mine	0.79	Moderate	---	---	Eger et al., 2006
Front end Loader	South African Mine	4.2	High	---	---	Van Niekerk et al., 2000
Dumper	coal mine	1.10	High	13.84	moderate	Mandal and Srivastava, 2010
LHD (3.5 yard)	underground gold mine	1.12	High	---	---	Eger et al., 2006
LHD (3.5 yard)	underground mine	2.25	High	---	---	Village et al., 1989[3]
LHD (1.5-4 yards)	underground gold mine	1.7	High	34.0	high	Eger et al., 2011
LHD (3-6 yards)	underground gold mines	0.97	High	22.96	high	Eger et al., 2013
LHD (5 yard)	underground mine	1.04	High	---	---	Village et al., 1989
LHD (6 yard)	underground mine	1.6	High	---	---	Village et al., 1989
LHD (7 yard)	underground nickel mine	0.52	Moderate	---	---	Eger et al., 2006
LHD (8 yard)	underground mine	1.24	High	---	---	Village et al., 1989[3]
LHD (6-11 yards)	underground nickel mine	0.74	Moderate	17.41	high	Eger et al., 2008
LHD(6-11 yards)	underground nickel mines	0.82	Moderate	19.94	high	Eger et al., 2013
LHD (8-11 yards)	underground nickel mine	1.0	High	22.5	high	Eger et al., 2011
Articulated haul Truck	South African Mine	3.4	High	---	---	Van Niekerk et al., 2000
Hydraulic Face Shovel	South African Mine	4.4	High	---	---	Van Niekerk et al., 2000

Summary of vibration exposure limits and guidelines for 8 – hour duration ISO-2631-1997

Assessment of Health Risks	Predicted Health Risks	RMS acceleration, A(8), m s^{-2}	Vibration dose value, VDV(8), m $s^{-1.75}$
“For exposures below the health guidance caution zone, health effects have not been clearly documented”	Low	<0.45	<8.5
“…in the health guidance caution zone, potential health risks is indicated”	Moderate	0.45-0.90	8.5-17
“…above the health guidance caution zone, health risks are likely”	High	>0.9	>17

Eger et al., 2008

EVALUATION METHOD

Whole-Body Vibration Standard ISO 2631-1

General Requirements:

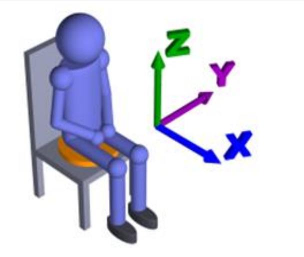
- ISO 2631-1 covers methods for the measurement of periodic, random and transient vibration with regard to health.

- The considered frequency range is 0.5 to 80 Hz

- Measured is frequency weighted root-mean-square acceleration

- Applicable for vibrations transmitted to the body as a whole through the supporting surfaces: the feet of a standing person, the back and the feet of a seated person, the buttock or the supporting surface of a recumbent person.

- Vibration is measured tri-axial with a coordinate system originating at the point from which vibration enters the body. The Z axis always runs along the spine.



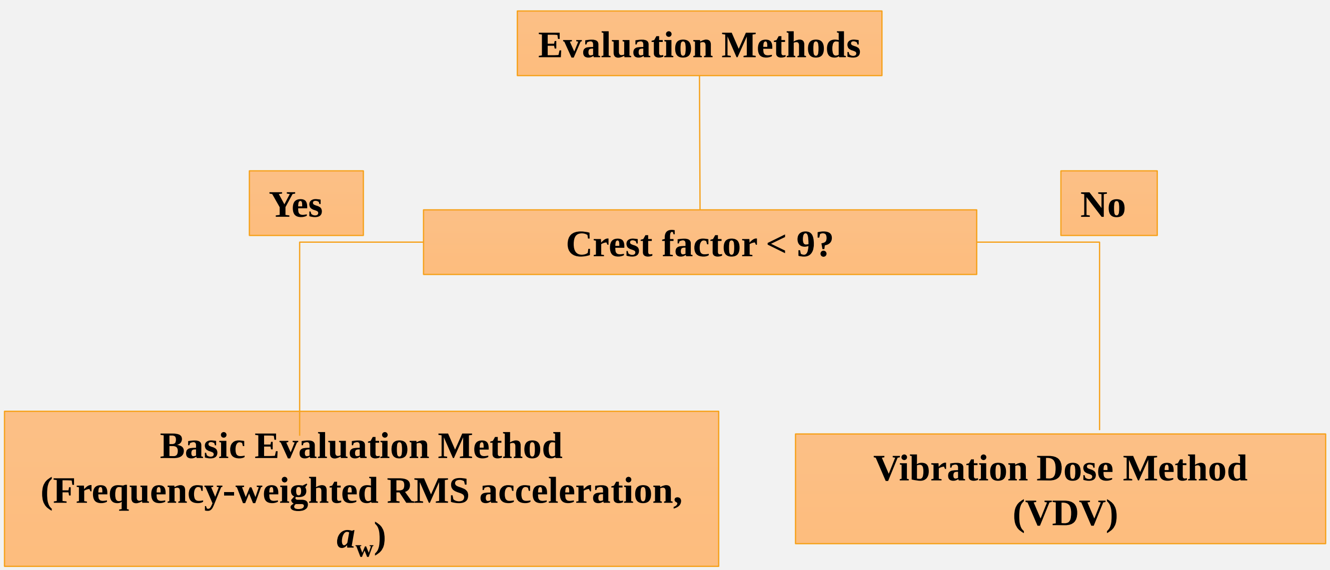
EVALUATION METHODS

- The selection of appropriate evaluation methods depends on the amount of shocks and transient vibration in the measured signal.

- This is measured through crest factor (**CF**):

$$\mathrm{CF} = \frac{\max[a_w(t)]}{\mathrm{RMS}\ (a_w)}$$

- The basic evaluation method shall be used for evaluation. In cases where one of the alternative methods is used, both the basic and the alternative evaluation value shall be reported.



Whole-Body Vibration Standard ISO 2631-1: 1997

Basic Evaluation Method:

- For vibration with low contents of shocks (crest factor < 9)

- Measured is the RMS of frequency weighted acceleration in m/s^2

$$a_w = \sqrt{\frac{1}{T}\sum_{i=0}^{T} {a_i}^2}$$

where

a_i is the instantaneous frequency weighted acceleration at a particular time t, m s^{-2}.

T is the duration of measurement, s.

a_w is Frequency-weighted RMS acceleration over a time period, m s^{-2}

- In the presence of occasional shocks or transient vibration, i.e. high crest factors, the basic evaluation method may underestimate the effects of whole-body vibration.

Daily Exposure, A(8)

A(8) is a measure of the total predicted vibration exposure for an eight-hour workday.

The daily exposure of 8 hours duration for frequency-weighted RMS acceleration is calculated by the equation given below.

$$A(8) = a_{wd}\sqrt{\frac{T}{8}}$$

Where,

A(8) = Daily RMS acceleration, m s^{-2}

a_{wd} = Measured acceleration magnitude of vibration along dominant axis, m s^{-2}

T = Vibration exposure time, h

Whole-Body Vibration Standard ISO 2631-1-1997

Fourth Power Vibration Dose Method (VDV):

- More sensitive to peaks than the basic evaluation method by using the fourth power instead of the second power of acceleration

- The result is called Vibration Dose Value (VDV) which has the unit $m/s^{1.75}$

$$\mathrm{VDV} = \left\{ \sum_{i=0}^{T} a_i^4 \right\}^{\frac{1}{4}}$$

where

a_i is the instantaneous frequency weighted acceleration at a particular time t, $m\ s^{-2}$

T is the duration of measurement, s.

VDV is Vibration dose value, $m\ s^{-1.75}$

Daily VDV Exposure, VDV(8)

The daily vibration exposure of 8 hours equivalent for VDV can be calculated by using the following expression as given below.

$$VDV(8) = VDV \times \sqrt[4]{\frac{T_{\text{exp}}}{T_{\text{meas}}}}$$

Where,

VDV (8) = Daily VDV exposure, m $s^{-1.75}$

VDV = Vibration dose value, m $s^{-1.75}$

T_{exp} = Duration of exposure.

T_{meas} = Duration of VDV measurement.

FIELD INVESTIGATION

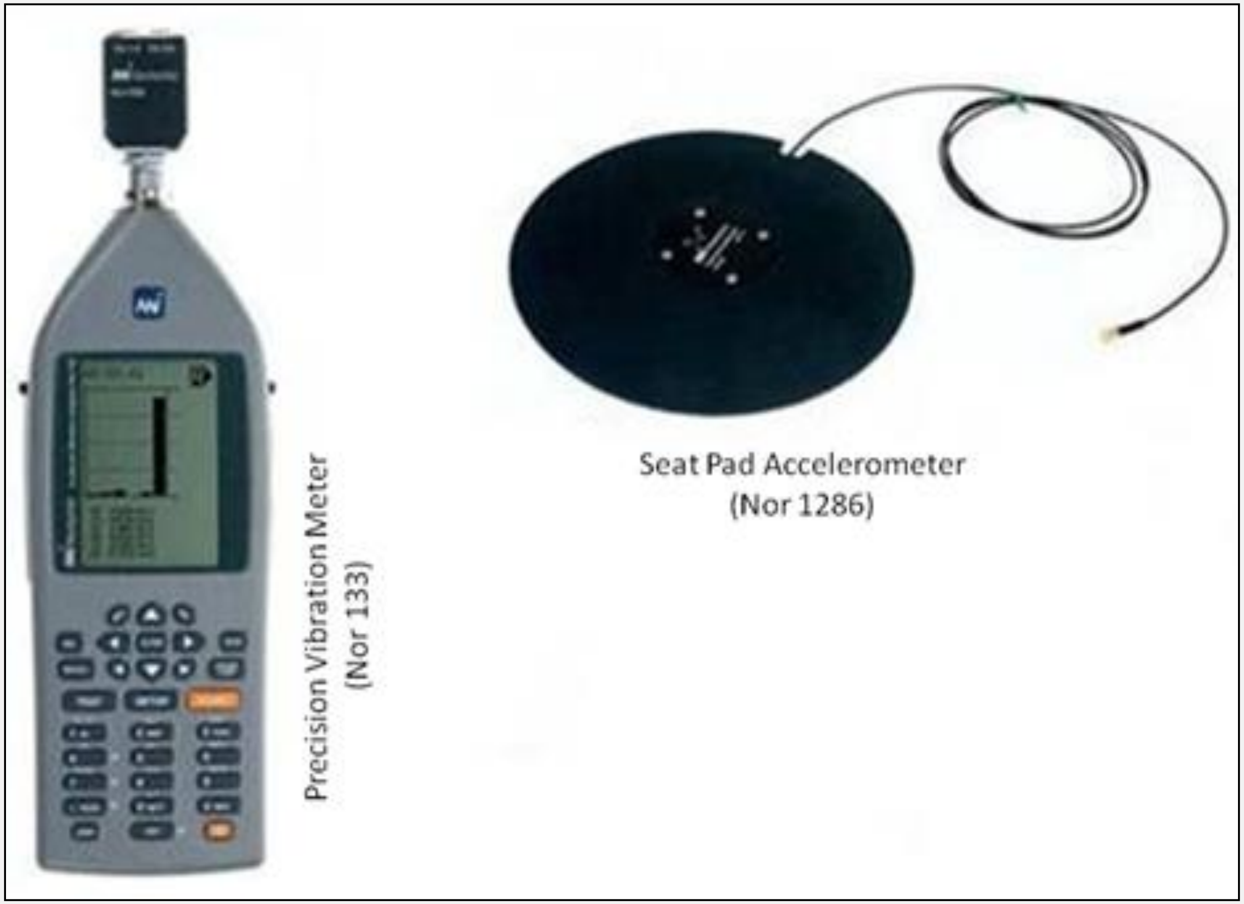
- WBV exposure measurements were performed according to the standard procedure described in ISO 2631-1(1997) guidelines. A tri-axial seat pad accelerometer (Model no.: Nor 1286) was placed on the seat of machine operator in accordance with the ISO 2631-1(1997) guidelines with regards to direction and anatomical positioning.

- Vibration was measured in a three-axis coordinate system that takes into consideration points of entry of the vibration in the human body. Accelerometer was connected to a precision vibration meter (Model no: Nor133) designed in accordance with ISO 8041 (1990).

- In this study, in order to get a representative period of vibration exposure, measurements were taken up for a cycle.

MEASURING WHOLE-BODY VIBRATION

WBV is measured in accordance with ISO 2631-1: 1997

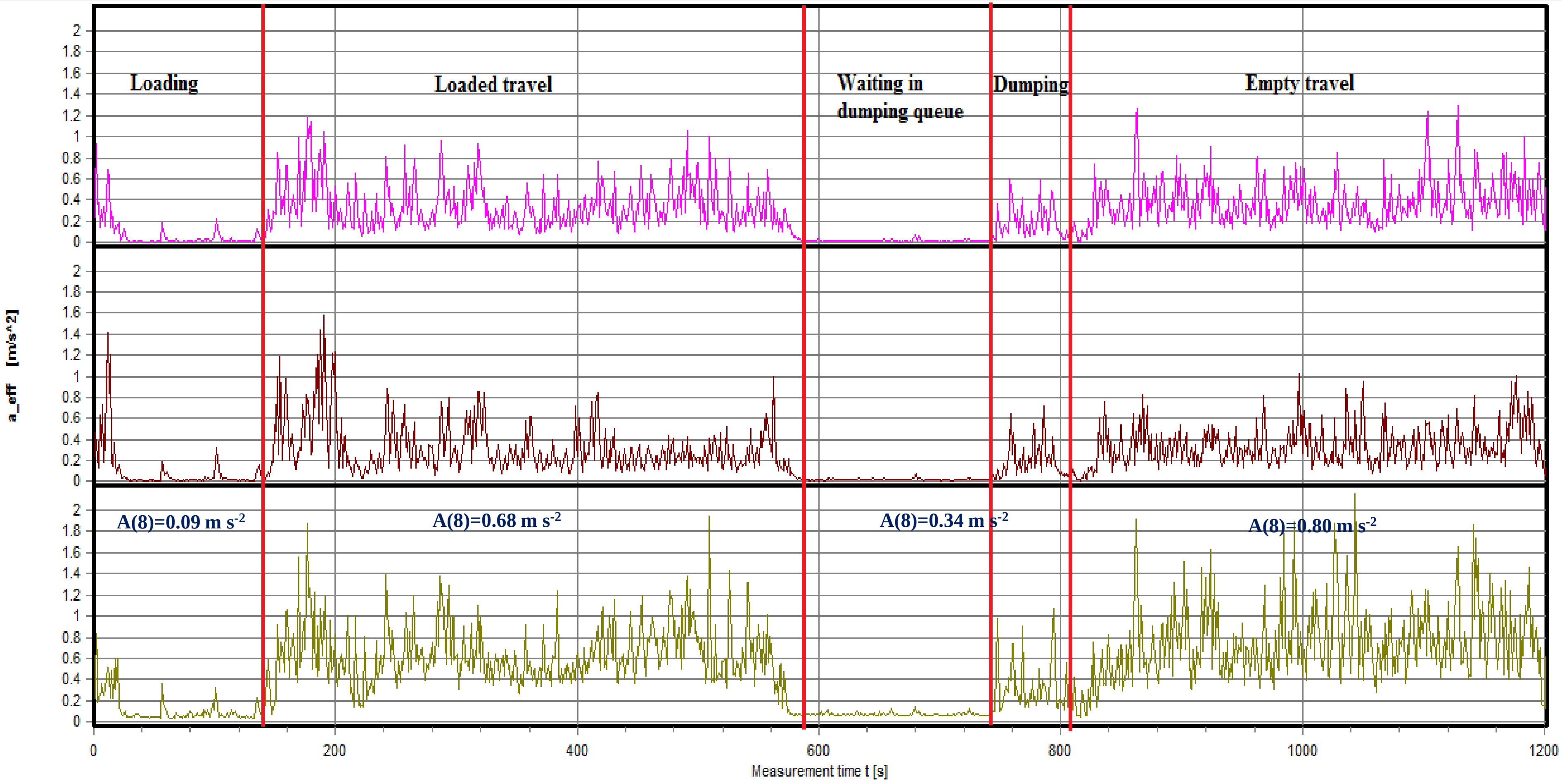


Seat pad accelerometer and Precision vibration meter

WBV EXPOSURE OF SOME DUMPER OPERATORS IN MINES

100 tones dumper-coal mines

WHOLE-BODY VIBRATION EXPOSURE OF A DUMPER OPERATOR IN A COAL MINE (Time dependent frequency weighted RMS Acceleration, t=1s)



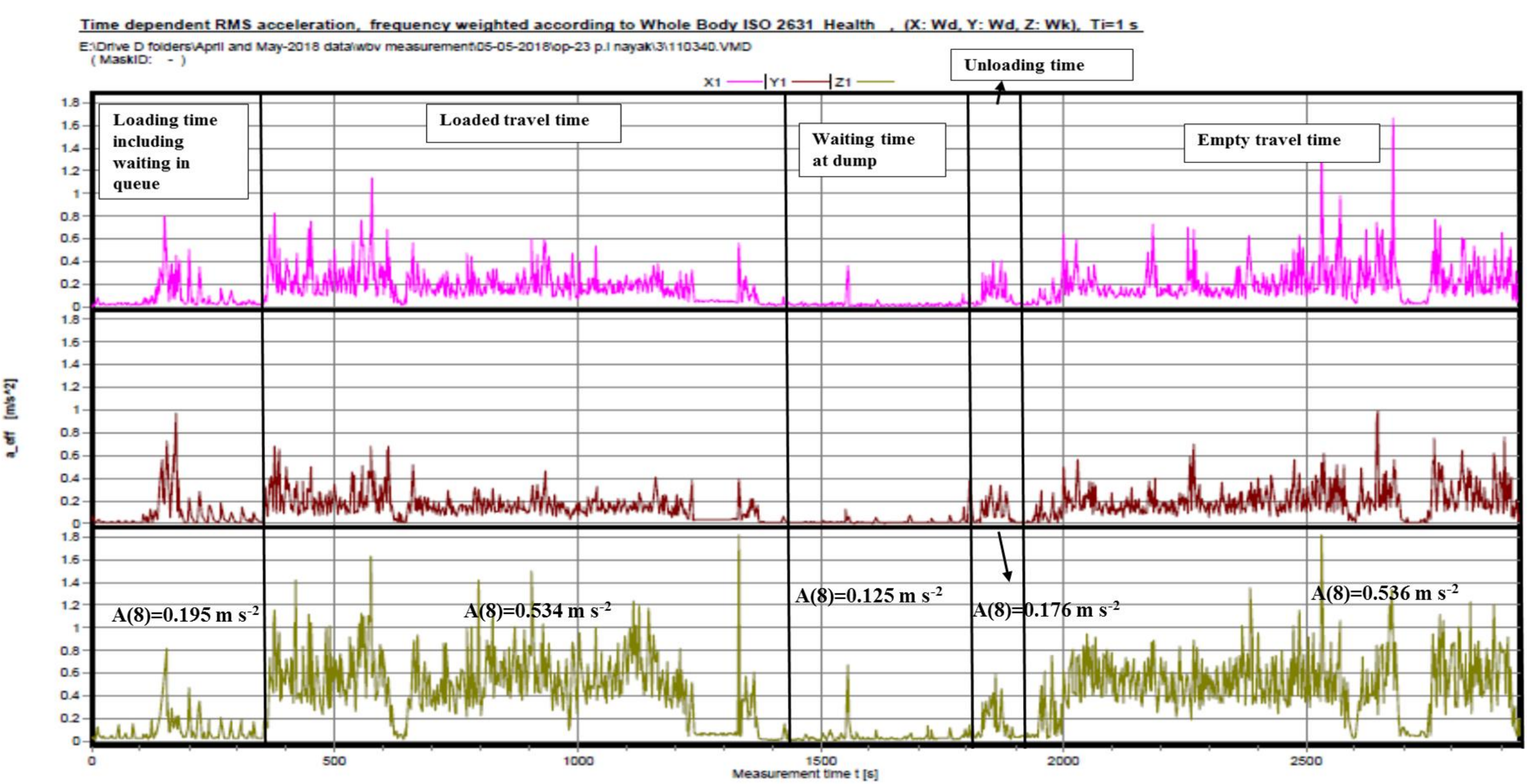
Results for a 100 tone dumper in a coal mine

OUTPUT SCREEN OF WHOLE-BODY VIBRATION EXPOSURE MEASURES OF NORSONIC TRI-AXIAL VIBRATION ANALYZER

		X1	Y1	Z1			
a_w	[m/s^2]	0.3459	0.3316	0.6189			
MTVV	[m/s^2]	1.286	1.58	2.154			
Point in time MTVV	[s]	1129	190.4	1044			
VDV	[m/s^1.75]	3.286	3.213	6.027			
VDV/(a_w*T^1/4)	[]	0.729	0.744	0.748			
MTVV/a_w	[]	3.72	4.77	3.48			
Crest factor	[]	7.35	7.13	8.98			
Reduction (Z)	[%]	-					
A(8)-Norm		EN 2002-44EG a_					
daily impact duration	[min]	480					
a_we	[m/s^2]	0.6189					
A(8)	[m/s^2]	0.6189					
Orient_max		Z					
t_expos	[min]	1440					
t_action	[min]	313					

100 tones dumper- iron ore mines

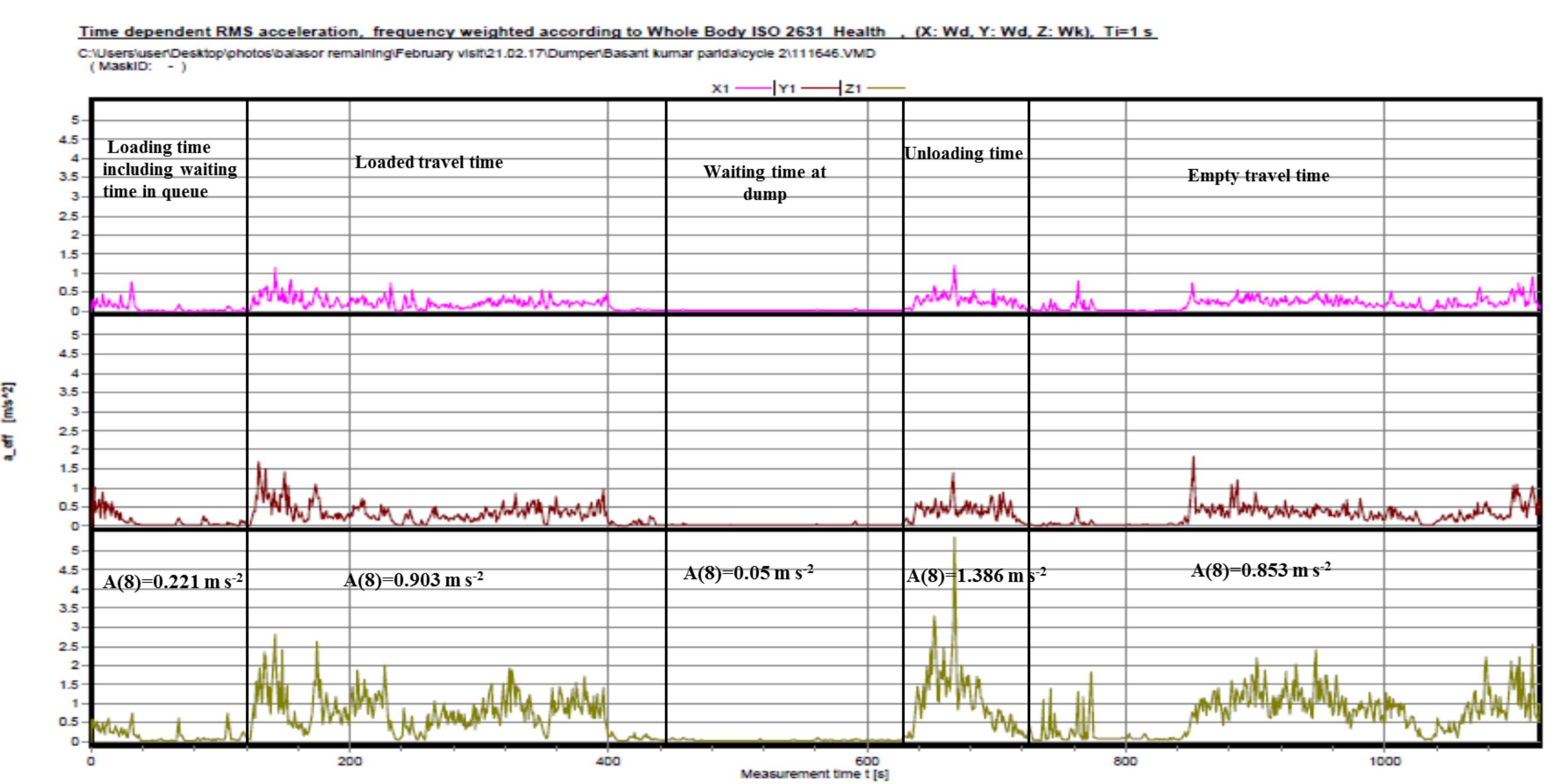
WHOLE-BODY VIBRATION EXPOSURE OF A DUMPER IN AN IRON ORE MINE (Time dependent frequency weighted RMS Acceleration, t=1s)



Results for a 100 tones dumper in an iron ore mine

50 tones dumper- chromite mine

WHOLE-BODY VIBRATION EXPOSURE OF A OPERATOR IN A CHROMITE ORE MINE (Time dependent frequency weighted RMS Acceleration, t=1s)



Results for a 50 tones dumper in a chromite mine

Parameters	Mine Type	Mean	% of operators below the lower limit of ISO 2631-1: 1997	% of operators between upper and lower limit of ISO 2631-1: 1997	% of operators above the upper limit of ISO 2631-1: 1997
Frequency-weighted RMS Acceleration (m s^{-2})	Coal Mine		< 0.45 m/s^2	0.45 - 0.90 m/s^2	> 0.9 m/s^2
Daily RMS exposure, A(8)		0.6304	4.25	95.74	0.00
Crest Factor			< 9.0		> 9.0
CFx		8.99	51.06		48.93
CFy		8.11	78.72		21.27
CFz		11.30	8.51		91.48
Vibration Dose Value (m $s^{-1.75}$)			< 8.5 $m/s^{1.75}$	8.5 – 17 $m/s^{1.75}$	> 17 $m/s^{1.75}$
Daily VDV Value, VDV (8)		13.845	2.12	80.85	17.02
Frequency-weighted RMS Acceleration (m s^{-2})	Iron Ore Mine		< 0.45 m/s^2	0.45 - 0.90 m/s^2	> 0.9 m/s^2
Daily RMS exposure, A(8)		0.4713	43.11	56.89	0.00
Crest Factor			< 9.0		> 9.0
CFx		11.20	12.06		87.94
CFy		10.54	18.96		81.04
CFz		14.88	0.00		100.00
Vibration Dose Value (m $s^{-1.75}$)			< 8.5 $m/s^{1.75}$	8.5 – 17 $m/s^{1.75}$	> 17 $m/s^{1.75}$
Daily VDV Value, VDV (8)		10.76	8.62	89.66	1.72
Frequency-weighted RMS Acceleration (m s^{-2})	Chromite Mine		< 0.45 m/s^2	0.45 - 0.90 m/s^2	> 0.9 m/s^2
Daily RMS exposure, A(8)		0.8723	0.00	50.00	50.00
Crest Factor			< 9.0		> 9.0
CFx		9.61	0.00		100.00
CFy		7.42	100.00		0.00
CFz		9.76	0.00		100.00
Vibration Dose Value (m $s^{-1.75}$)			< 8.5 $m/s^{1.75}$	8.5 – 17 $m/s^{1.75}$	> 17 $m/s^{1.75}$
Daily VDV Value, VDV (8)		18.64	0.00	50.00	50.00

CONCLUSIONS

- Whole-body vibration exposure is an emerging issue for the Indian mining industry and needs to be managed properly to enhance the occupational health issues of mine workers.
- DGMS has already initiated proactive measures in this direction. To address this issue, the 11th National Conference of Safety in Mines has recommended the vibration studies of HEMM operators and ergonomic assessment of machineries.
- Assessment of whole-body vibration exposure of HEMM operators and ergonomic assessment of various work processes, seat design, working postures will certainly improve the health, safety and operational efficiency of workers.
- Several vibration studies of HEMM operators carried out by the Mining Engineering Department of IIT Kharagpur have revealed that rollers, graders, dozers and dumper operators are exposed to moderate to high health risk.
- There is an urgent need for all the mines to pay immediate attention to address this major health issue of machine operators..

THANK YOU