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Influence of Some Mechanical Factors on Whole-body Vibration (WBV) for 100-tonne Dumpers

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Abstract: Mining involves frequent and intensive usage of heavy machinery, namely dumper, drill, shovel, dozer and dragline. Whole Body Vibration (WBV) is a point of concern for HEMM operators when a human is supported by a surface, which is vibrating and the vibration is transmitted mechanically to the body parts. Prolonged exposure to overdose of whole body vibration may cause different health problems namely musculoskeletal disorder (MSD), sleep disorder and headache. In India, the number of miners regularly exposed to WBV ranges from 1.80 lakhs to 18 lakhs and are at risk of WBV related health consequences. In this present paper whole body vibration related issues for the 100-tonne capacity dumper operation is discussed. WBV related to dumping operation is influenced by different machine related and operation related factors, namely speed of vehicle, vehicle load, type of vehicle, tires of vehicle, type of seat, seat and cabin suspension, location of cabin, vehicle maintenance. Personal factors such as age, height, weight, and lifestyle factors also affect the WBV exposure of an individual. However in this present paper, keeping the dumper similar, only the operational parameters are allowed to vary to observe their relative influences on WBV. The load of the dumper and speed of the dumper are considered as the major influencing parameters. WBV is measured using a tri-axial accelerometer based piezo-electric sensors. The measured data are analyzed using NorVibraTest software equipped with frequency weighting as per ISO, 1997 standard. Altogether 21 dumpers, each for 6 cycle operation, are experimented with WBV measurement studies. A simple correlation analysis between WBV and speed of the dumper reveals a significant positive relationship. Whereas, no significant relationship has been found between WBV and load of the dumper though a slight negative trend is observed. Assessment of health risk based on daily exposure of vibration dose value, VDV (8), shows that 76% dumper operators are at moderate health risk and 24% of the operators are at high health risk (considering total exposure duration of 7 hours). It is also found that the crest factor for the dominant axis exceeds more than 9 on many occasions.

Keywords: acceleration, crest factor, dumper, surface mining, VDV, Whole-body Vibration

1. Introduction

Mining is a primary industry which involves excavation of billions of tons of rock. Majority of these productions are coming from the surface mining. Thus, surface mining deploys large and heavy earth moving machines. These machines have to operate in a rugged conditions and hence empowered with high engine power. This generates high level of vibration on its own body and leads the operator subjected to experience vibration along his spine, which is termed as Whole-body Vibration (WBV). WBV may be defined as, when a human is supported by a surface, which is vibrating and the vibration is transmitted mechanically to the body parts (Mansfield, 2005). A prolong exposure to a significant level of WBV may lead to different health problems namely musculoskeletal disorder (MSD), sleep disorder and headache (Slota et al., 2008). Whole body vibration becomes a point of concern since last few decades and is become a mandatory part of ergonomic study.

Dumper is a common transporting machine used in surface mines and its size depends on planned capacity of the mine. Capacity of the dumpers, in Indian surface mines, varies from 8 tonne to 270 tonne. This present paper reports the whole body vibration related issues for the 100-tonne capacity dumper operation in a surface coal mine of Eastern India.

2. Retrospect WBV Issues

Whole Body Vibration occurs when a human is supported by a surface that is vibrating and the vibration transmits to the body through its skeleton and affects the body parts mainly due to fatigue, jerk, moments to the tissues, bones and muscles. The vibrations are transmitted to the body from the machines through (i) the seat, when whole body vibration of the operator is induced, (ii) manual controls and the steering wheel, when vibration in upper limbs of the operator is induced, (iii) through the supports and the floor of the cab as well as foot controls, when mostly local vibrations in lower limbs of the operator are induced (Petrovic et al., 2005).

Generally, high magnitude of vibration has greater potential to damage human body than the low one. However, human body is not equally sensitive to each frequency as each part of a human body has different circular natural frequency. On receiving a vibration of same frequency range, resonance occurs at that part of the body and causes more amount of damage. So, the adverse effects of vibration to the human body cannot be reported properly by only considering the magnitude of the vibration. Frequency weightings are thus applied to time-domain signals to modify them so that the weighted signal represents the human response to the vibration rather than the mechanical characteristics of the vibrating surface. The frequency range within which human body respond more, more weightage is given to that frequency range of the acceleration (Mansfield, 2005). It was observed that a seated human is 10 times more sensitive to vibration at 5 Hz than at 100 Hz. Therefore, it could be proposed that measurements of vibration at 100 Hz are reduced by a factor of 10 when compared to measurements of vibration at 5 Hz, in order to maintain subjective sensation parity between the two measures (Parsons and Griffin, 1988).

Whole body vibration is measured in three perpendicular axes. Most exposures to whole body vibration occur in seated postures while people are driving or passengers are sitting in vehicle in motion (Benson and Dilnot, 1981). Therefore, WBV is mainly measured in seated postures. Vibration can occur in different frequency and magnitude. Magnitude of WBV is evaluated in two basic ways. One is calculating the root mean square (RMS) value of the acceleration and another is the fourth root of the integral of the fourth power of acceleration named as vibration dose value (VDV). Frequency of WBV is expressed in Hz. ISO 2631-1:1997 (Mechanical vibration and shock: Evaluation of human exposure to whole body vibration—Part 1: General requirements); reports the vibration measurement procedure, frequency weighting of the measurement signals and evaluation of the vibration dose and the standard allowable exposure level.

A number of researchers studied about the occurrences of WBV and their influencing parameters. A summary of some of their works is given in Table 1. Thus, it is evident that WBV related to dumping operation is influenced by different machine related and operation related factors, namely, speed of vehicle, vehicle load, type of vehicle, tires of vehicle, type of seat, seat and cabin suspension, location of cabin, vehicle maintenance (Tiemessen et al., 2007). Personal factors such as age, height, weight, and lifestyle factors also affect the WBV exposure of an individual. However in this present paper, keeping the dumper similar, only the operational parameters are allowed to vary to observe their relative influences on WBV. The load of the dumper and speed of the dumper are considered as the major influencing parameters. The effects of personal factors are kept out of the scope of present paper.

Table 1. WBV related to dumper operation and some key influencing parameters (Pati S, 2016)

Parameters	*Studied by*	*Findings*
Body weight of operators	Boileau and Rakheja (1990)	Inconsistent results
	Malchaire et al. (1996)	Strong negative relationship with WBV
Experience of operators	Ozkaya et al. (1994)	Negative relationship with WBV but not significant
	Chen et al. (2003)	Negative significant relationship with WBV
	Rehn et al. (2005)	Negative significant relationship with WBV only when loaded condition
Posture of the driver	Hinz et al. (2002)	Vibration magnitude at the seat was significantly higher when leaning backward or forward than when sitting in an upright position

Driving speed	Malchaire et al. (1996)	Strong positive relationship with WBV
	Sorainen and Rytkönen (1999)	Positive relationship with WBV at low frequencies
	Chen et al. (2003)	Quadratic trend of WBV- speed relationship
	Hostens and Ramon (2003)	Strong positive relationship with WBV up to a certain speed
	Cvetkovic and Prascevic (2005)	Increasing of WBV with increasing speed
	Rehn et al. (2005)	No relationship found
Vehicle weight	Nishiyama et al. (1998)	Negative relationship with WBV but not significant
Load on vehicle	Rehn et al. (2005)	Negative significant relationship with WBV
Tire pressure	Sherwin et al. (2004).	Increased tire pressure after a certain value, significantly increase WBV
	Scarlett et al. (2005)	Type of tires (radial or bias), lateral stiffness of the tire and the pressure in tires are influencing WBV

3. WBV of Dumpers – A Case Study

A surface coal mine is selected for analyzing the WBV related issues of dumping operation. The 100-tonne capacity dumpers are operating in the mine for transporting coal and overburden, mainly comprising of sandstone and shale. The mine is practicing top slicing method of mining with back filling. The dumpers are loaded mainly with shovel, which in general takes 3 to 4 bucket cycle to fill a fleet. The mine comprises 34 similar dumpers, amongst which 21 dumpers are selected for this experiment with 34 operators.

WBV is measured using a tri-axial accelerometer based piezo-electric sensors. The measured data are analyzed using NorVibraTest software equipped with frequency weighting as per ISO, 1997 standard. The data measured are -

aw: The effective value of the evaluated acceleration as an arithmetic mean over the whole measurement time.

VDV: Vibration Dose Value. The total energy transferred in an axis over the whole measured time.

CF: Crest Factor. Ratio of maximum vibration to root mean square acceleration.

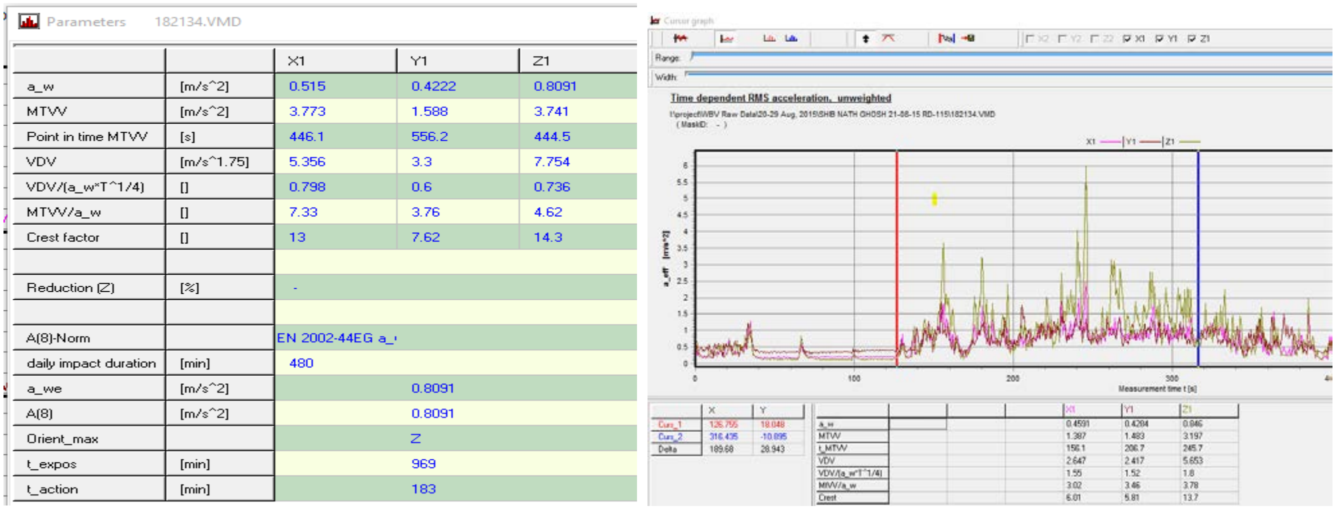
MTVV: Maximum Transient Vibration Value.

Altogether 21 dumpers, each for 6 cycle operation, are experimented with WBV measurement studies. During the 6 cycle measurement, the operator is kept unchanged. The effect of personal factor is not within the scope of this paper. The measured data are clustered for different ranges and given in Table 2. A sample output of the measured frequency weighted data is shown in Figure 1.

Table 2. Characteristics of WBV exposure of 34 dumper operators with operational parameters (Pati S, 2016)

Parameters	Mean	Median	SD	Range		% of values below Lower limit	% of values between upper and lower limit of ISO 2631-1: 1997	% of values above the upper limit
				Minimum	Maximum			
x-axis (a_{wx})	0.4220	0.4132	0.0746	0.3029	0.5505	67.65	32.35	0.00
y-axis (a_{wy})	0.3726	0.3778	0.0457	0.2695	0.4584	94.12	5.88	0.00
z-axis (a_{wz})	0.6869	0.6710	0.1131	0.4773	0.9142	0.00	97.06	2.94
Vibration total value (a_{wv})	1.0490	1.0695	0.1526	0.7960	1.3102			
Daily RMS exposure, A(8) (7 hrs. exposure time in a shift)	0.6425	0.6276	0.1074	0.4465	0.8551	2.94	97.06	0.00
x-axis (VDV_x)	3.3593	3.3467	0.6182	2.2391	4.9501			
y-axis (VDV_y)	2.8909	2.8867	0.5346	2.0921	4.5207			
z-axis (VDV_z)	5.6887	5.6865	1.1084	3.7923	8.1003			
VDV total value (*VDVtotal*)	5.9970	5.8984	1.1009	4.1537	8.3422			
Daily *VDV* value, *VDV* (8) (7 hrs. exposure time in a shift)	14.87	14.068	2.57	10.81	20.45	0.00	76.47	23.53
Cfx	8.44	8.21	2.32	4.86	14.50	64.705		35.29
Cfy	7.13	6.62	2.21	4.10	16.60	91.176		8.82
Cfz	11.83	10.65	6.25	7.13	44.70	26.47		73.52

As per ISO 2631-1: 1997 : Lower limit of $a_w = 0.45 m/s^2$, Upper limit of $a_w = 0.90 m/s^2$,
For crest factor in this case the limit is considered 9 (Pati S, 2016)



		X1	Y1	Z1
a_w	[m/s^2]	0.515	0.4222	0.8091
MTVV	[m/s^2]	3.773	1.588	3.741
Point in time MTVV	[s]	446.1	556.2	444.5
VDV	[m/s^1.75]	5.356	3.3	7.754
VDV/(a_w*T^1/4)	[]	0.798	0.6	0.736
MTVV/a_w	[]	7.33	3.76	4.62
Crest factor	[]	13	7.62	14.3
Reduction (Z)	[%]	-		
A(8)-Norm		EN 2002-44EG a_		
daily impact duration	[min]	480		
a_we	[m/s^2]		0.8091	
A(8)	[m/s^2]		0.8091	
Orient_max			Z	
t_expos	[min]		969	
t_action	[min]		183	

Figure 1. A sample of measured and analysed WBV data (Pati S, 2016)

A simple correlation analysis between WBV and speed of the dumper reveals a significant positive relationship. The relationship is shown in Figure 2a for loaded dumper and Figure 2b for empty dumper.

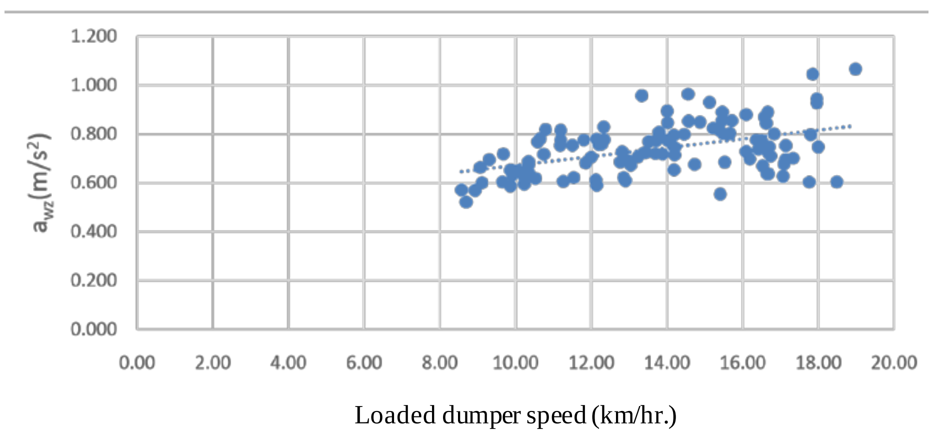


Figure 2a. Positive relationship between WBV and loaded dumper speed (Pati S, 2016)

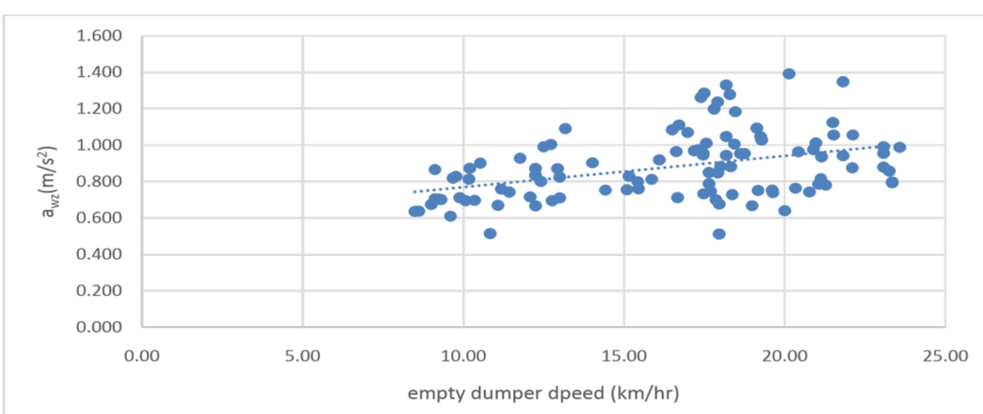
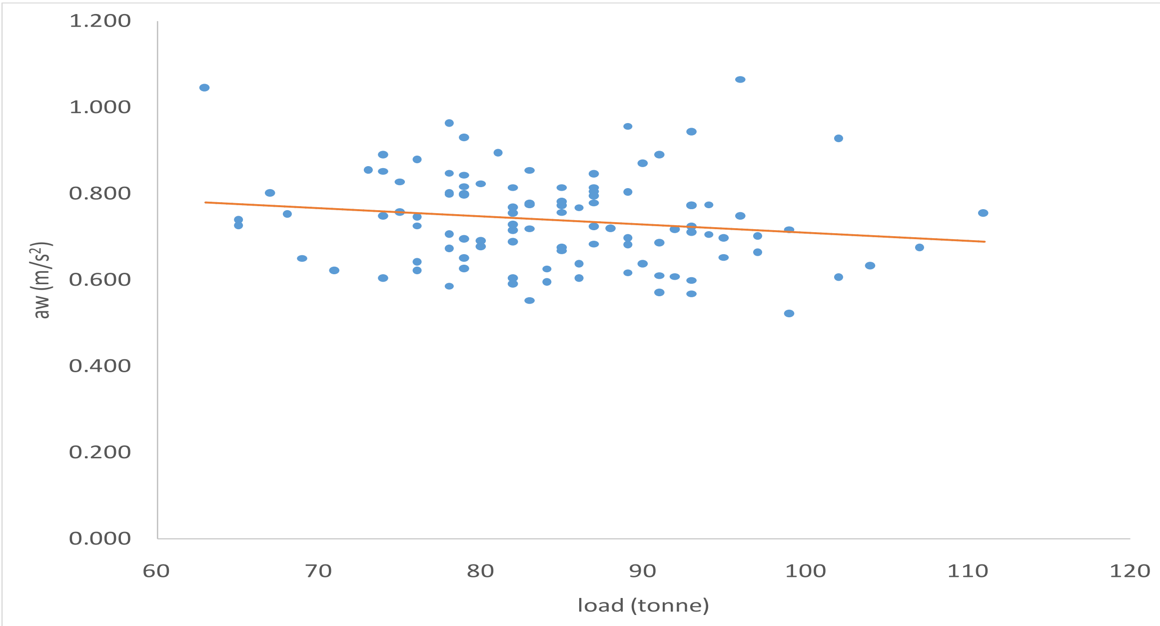


Figure 2b. Positive relationship between WBV and empty dumper speed (Pati S, 2016)

Similarly, a simple correlation analysis is carried out between WBV and load of the dumpers and no significant relationship between them would be established. However, a minor negative trend is observed. The plot of the WBV and load of the dumpers is given in Figure 3.



Data pertaining to daily exposure of vibration dose value, VDV (8), (in Table 2) show that 76% dumper operators are at moderate health risk and 24% of the operators are at high health risk (considering total exposure duration of 7 hours). It is also found that the crest factor for the dominant axis exceeds more than 9 on many occasions.

4. Conclusion

The present investigation reveals that the dumper operators of the mine are expose to the WBV significantly. Almost all the operators are exceeding the lower limit of WBV, however only few are exceeding the upper limit, thus indicating the moderate risk related to WBV influenced diseases. High crest factor indicates the risk related to shock at the spine of the body. This present study establishes a simple positive relationship between WBV and speed of the dumper for both loaded and empty run condition. Whereas, no significant relationship has been found between WBV and load of the dumper though a slight negative trend is observed.

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