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Evaluation of Transmissibility Factors of Pneumatic Dumper Seats Used in Indian Mines- A Pilot Study

BIBHUTI BHUSAN MANDAL[1]* and ANAND ARUN DESHMUKH[2]

[1]Department of Occupational Hygiene, National Institute of Miners' Health(NIMH), Ministry of Mines, Government of India, JNARDDC Campus, Amravati Road, Wadi, Nagpur- 440023, India.
[2]Department of Occupational Health, National Institute of Miners' Health (NIMH), Ministry of Mines, Government of India, JNARDDC Campus, Amravati Road, Wadi,Nagpur- 440023, India.

Abstract

Whole-body Vibration (WBV) is a well- known occupational health hazard in mining industry. Dumper operators are subjected to WBV generated from road-tyre interaction and transmitted through the base of the seat. Dynamic characteristics of vehicle seat are vital contributing factor in determining the quality of a seat in use. The objective of this pilot study was to evaluate the transmissibility factor of pneumatic dumper seats used in an Indian mine. Total fifteen (15) dumpers of two different makes with pneumatic seats were selected for the study purpose. The tri-axial seat-pad accelerometers (SVANTEK make SV 38A) collected data in all three orthogonal axes of translational or rectilinear vibration. The mono-axial or single axis accelerometer (SVANTEK make SV 80 with mounting magnet SA 32) was simultaneously positioned rigidly on the floor to record signals in vertical direction. The data so obtained were then calculated using a vibration risk calculator in MS-EXCEL to quickly predict the health impacts using the measured vibration magnitude along with period of exposure per day. The results obtained clearly indicated that the drivers of all the fifteen (15) dumpers are at moderate risk of adverse health effects. It was clear from the SEAT factor calculated using rms and VDV values that the present seats installed in all the dumpers are not efficient and failed to attenuate the vibrations from the floor to seat and ultimately to the body of the dumper operator. It was observed that further in-depth evaluation of engineering and designing part of the seats used in these types of dumpers is desirable. The future scope of such evaluations must take into consideration the actual working condition to be able to realistically attenuate the vibrations so as to provide comfort and relief to the dump operators in mines.

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CONTACT Bibhuti Bhusan Mandal ✉ bbmandal@gmail.com Department of Occupational Hygiene, National Institute of Miners' Health(NIMH), Ministry of Mines, Government of India, JNARDDC Campus, Amravati Road, Wadi, Nagpur- 440023, India

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Introduction

Mining industry is associated with many occupational health hazards which require monitoring and evaluation. Whole-body vibration (WBV) is one such hazard known for more than a century and widely discussed in various literatures due to its probable negative health impacts on working population[1-13].In surface mining of minerals, various heavy earth-moving machines are deployed for all major operations. All these machineries are more often sophisticated and technologically advanced. Transportation of minerals from blasted face to the crusher plant is one of the essential steps in the mining operations. Dumpers are being extensively used for transportation of minerals and overburden. The capacity of dumpers in Indian mines presently varies from about 10 to 240 tonnes.

Transportation of mineral is often outsourced to third party contractor by mine owners. Technical advancements in Indian mines are not uniform in nature; companies use ordinary flat trucks through the contractor. In top mining conglomerates this is coupled with their own dumpers of good quality like Volvo or Komatsu make dumpers for transportation. In either situation the task of driving vehicles and transporting minerals from mining lease area to crusher plant is economically driven and hence very often done even if adverse and strenuous conditions prevail. Vehicle type, suspension or quality of seats all vary in nature from mines to mines. Additionally condition of the haul road is site specific factor and is not always favourable for smooth driving at all. Dumper operators are thus exposed to WBV during transportation of mineral in a moving dumper.

Around fifty nine dumper operators (59) out of total sixty-six (66) were found to be exposed to vibration for at least six hours per day as cited in one study conducted by Mandal (2014) in Indian mines[14].The magnitude of health impacts of WBV are such that it has become a priority concern in mining sector to look into. Chronic exposure to WBV (0.5 to 80 Hz) manifests in many adverse health impacts on operators. Low back pain (LBP) is considered to be a well-known occupational health issue among vehicle operators exposed to WBV[6,2,15,16]. Such health disorders are certainly not desirable and lead to considerable financial compensation in many countries. Moreover, such diseased condition results in to a general degradation in the quality of life of mine workers.

Vibration is caused mainly by road-tyre interaction and reaches the operator's seat through one or more stages of vehicle suspension system. Primarily seats can be classified into two types, conventional and suspension seats. Conventional seats are usually made of steel frame, polyurethane foam cushions and a fabric covering. Sometimes additionally some features of these types of seats are adjustable such as seat height, backrest angle and fore-aft adjustment. However, important characteristic of conventional seats is the lack of its own independent suspension mechanism. Suspension seats however,consist of an independent suspension mechanism in addition to the conventional foam cushion. Suspension mechanism consists of springs and a damper mounted beneath the seat cushion.Figure 1 depicts the generic engineering design of a typical suspension seat[17].

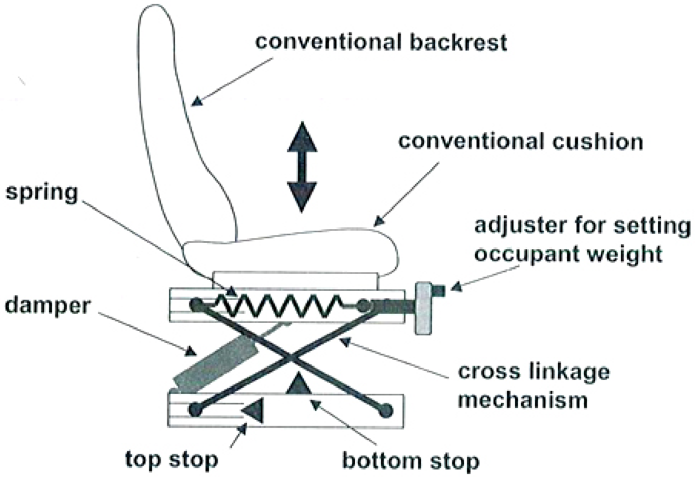

Fig. 1: typical suspension seat and its components (Mansfield, 2005)

Further, suspension seats can be categorised based on the type of suspension arrangement being provided. For instance, in this pilot study all the dumpers were provided with pneumatic suspension seats. Ebe and Griffin (2000a,b) considered static and dynamic factors for seat discomfort. As the vibration magnitude increases the relative importance of the dynamic characteristics also increases[18,19]. This has been given due consideration in the present study conducted under field conditions.

Mansfield (2005) points out that there are two primary options available for prevention of these operators from WBV exposure: either to reduce the duration or to lessen the magnitude of exposure[17]. Now, in an eight hours shift, it is not practicable to reduce the exposure to less than six hours. It would be unrealistic because of economic aspects of the mineral transportation by mining industry. In an economic scenario where the industry is more and more moving towards privatisation and where the labourers are increasingly resourced through contractual agencies, the actual exposure to vibration at work may even exceed eight hours due to extended period of work. As a consequence, the only option that would be left for mitigation of risk from vibration is to reduce the intensity of vibration entering in to the human body. For doing so and designing of engineering controlled measure or preventive strategy, efficacy of the seats installed in the dumpers in regard to the transmissibility of vibration from the source to the human body needs to be evaluated. The basic objective of this preliminary investigation is to evaluate transmissibility factor of pneumatic dumper seats used in the mining lease area under study. Seat Effective Amplitude Transmissibility or SEAT factor of pneumatic seats of total fifteen (n=15) dumpers has been calculated in dynamic field condition.

Material and Methods

Selection of Dumpers and Seats For Real-Time Experiment

Two types of dumpers were selected for the study. Seat type of all the fifteen (15) dumpers was pneumatic. All the seats were integral part of the dumpers of respective make which are adjustable to the operator's weight. Such adjustments of height and inclination of backrest is supposed to be a standard practice. The details of the dumpers used for the preliminary assessment along with information about the seats are listed in Table 1. According to B B Mandal (2010 & 2014) most dumpers on mining haul roads have vertical or the z axis as their dominant axis of vibration other than in some exceptional cases[15]. In regard to spinal health of people exposed to vibration at work, a specific international standard ISO 2631-5: 2004 has been issued which deals only with z-axis vibration[20]. Hence it was decided to measure z-axis vibrations on the base (floor) as well as on the seat surface of the dumpers in the mine.

Instrumentation and Measurement

The international standards ISO 8041:1990 &ISO 2631-1:1997 were followed for measurement of vibration and interpretation of data. A tri-axial seat-pad accelerometer (Figure 2) was placed on the seat between the operator's is cheal tuberocities (two parts of the buttock) for recording vibration on the seat surface in three directions (x, y & z).

The x-axis was aligned in the back to front direction, the yaxis in the right to left lateral direction, and the z-axis in the vertical direction. Since the study was targeted for understanding transmissibility of vibration signals in z axis, another mono-axial accelerometer (represented as z') was vertically placed on the floor with a strong magnetic mounting tofirmly attach with the metallic base (floor). A part of the floor carpet was occasionally removed from the cabin floor to get access to the metallic floor for magnetic attachment (Figure 3).

The tri-axial seat-pad accelerometers (SVANTEK make SV 38A) collected data in all three orthogonal axes of translational or rectilinear vibration. The mono-axial or single axis accelerometer (SVANTEK make SV 80 with mounting magnet SA 32) was simultaneously positioned rigidly on the floor to record signals in vertical direction. Vibrationsignals from the seat-operator interface was recorded for a complete cycle of operation i.e. loading, hauling, dumping and the dumper's return to the loading point. Run time of one cycle was taken into consideration for the purpose of one observation. The average time of observation was around 7 minutes for one cycle which excludes the period for which the dumper remained idle for any reasons.

Table 1: Details of Dumpers and seat studied along with static and dynamic elements affecting the WBV and SEAT factors

Equipment	Make	Model	Capacity	Seat Type	Weight of Operator (Kg)	Experience of operator years	Operators Age	Dynamic-Conditions	Remark	Characteristics of seat Road Type
Dumper –10	Komatsu	HD 465-7	55 MT	Pneumatic	95	18	34	Inclined, Horizontal and Bumpy	Seats were adjusted as per convenience and comfort of operator. The actual weight of the operator was not taken into consideration	All the seats were inbuilt seats of respective make the operator's weight provided as standard
Dumper – 11	Komatsu	HD 465-8	55 MT	Pneumatic	82	20	49	Inclined, Horizontal and Bumpy		
Dumper – 12	Komatsu	HD 465-9	55 MT	Pneumatic	82	21	43	Inclined, Horizontal and Bumpy		
Dumper – 13	Komatsu	HD 465-10	55 MT	Pneumatic	54	2	29	Inclined and Horizontal		
Dumper – 14	Komatsu	HD 465-11	55 MT	Pneumatic	57	8	46	Inclined, Horizontal and Bumpy		
Dumper – 15	Komatsu	HD 465-12	55 MT	Pneumatic	80	6	42	Inclined and Horizontal	Seat was adjusted at around 90 kg.	
Dumper – 16	Komatsu	HD 465-13	55 MT	Pneumatic	56	2	29	Inclined and Horizontal		
Dumper – 17	Komatsu	HD 465-14	55 MT	Pneumatic	64	8	38	Horizontal and Bumpy	Seats were adjusted as per convenience and comfort of operator. The actual weight of the operator was not taken into consideration	
Dumper - 20	Komatsu	HD 465-17	55 MT	Pneumatic	55	6	24	Horizontal and Bumpy		
Dumper - 23	Komatsu	HD465-7E0	55 MT	Pneumatic	120	21	42	Horizontal and Bumpy		
Dumper - 25	Caterpillar	770G	40 MT	Pneumatic	82	20	49	Horizontal and Bumpy		
Dumper - 28	Caterpillar	773E	60 MT	Pneumatic	60	5	40	Inclined, Horizontal and Bumpy		
Dumper - 31	Caterpillar	773E	60 MT	Pneumatic	75	10	43	Mostly Horizontal		
Dumper - 32	Caterpillar	773E	60 MT	Pneumatic	59	10	39	Mostly Horizontal		
Dumper - 33	Caterpillar	773E	60 MT	Pneumatic	72	6	32	Mostly		

Table 2: Calibration data of accelerometers

Seat pad Accelerometer SV38A (mV/g)			Uni-axial Accelerometer SV80 (mV/g)
x axis	y axis	z axis	z' axis
101.6	100.5	101.3	102.6

Fig. 2: A tri-axial seat-pad accelerometer placed on the seat of the operator

Fig. 3: SV80 mono-axial accelerometer magnetically secured to the floor of the driver's cabin

Since the operation is similar and repetitive, one cycle of operation was taken as representative of all other cycles (trips) in a day. Time taken for one cycle was multiplied by the number of trips to find out the total duration of exposure in a day for that operator[21]. All four accelerometers were calibrated prior to the commencement of testing in accordance with the calibration data supplied by the test laboratory (Table 2). Operators were instructed to continue with their routine work during the measurement session.

Prediction of Health Risk

To understand the severity of exposure that we are dealing with, we first collected the frequency-weighted root mean acceleration (RMS) values of seat vibration. Scale factors for seated exposures (W_d =1.4 for x and y axes, W_k = 1.0 for z axis) were applied to the RMS accelerations along all three axes. We developed and used a vibration risk calculator in MS-EXCEL to quickly predict the health impacts using the measured vibration magnitude along with period of exposure per day. For this purpose, we calculated the A(8) values for comparison with exposure limits in accordance with ISO 2631-1:1997 Standard[22] (Table 3). The Directorate General of Mines Safety in India (DGMS) stipulates guidelines to follow ISO Standards[23]. Exposure Action Values and Exposure Limiting Values are commonly expressed in terms of A(8) values. A(8) values are normalized by determining an eight hour exposure equivalent which is derived by the formula:

$$A(8) = ka_w\sqrt{\frac{T}{T_0}}$$

where, a_w is the measured vibration magnitude (RMS frequency-weighted acceleration magnitude) in one of the three orthogonal directions, x, y and z, at the supporting surface;

T is the duration of exposure to the vibration magnitude a_w;

T_0 is the reference duration of 8 hours, and

k is a multiplying factor (k= 1.4 for x and y axes and 1.0 for z axis). The highest A(8) value among x, y and z axis should be used to compare with limiting values[24].

Measurement of Transmissibility

The transmissibility of the WBV from the floor to the seat was evaluated using the seat effective amplitude transmissibility (SEAT) values. SEAT values are the ratio of the intensity at the seat to that of the WBV at the floor. A typical rigid seat would show a SEAT value of unity. SEAT values are usually evaluated using both RMS and VDV values. Mansfield (2005) precisely defined transmissibility as the ratio of the vibration on the seat surface to the vibration at the seat base (usually the floor of the vehicle) as a function of frequency:

$$T(f) = \frac{a_{\text{seat}}(f)}{a_{\text{floor}}(f)}$$

where, T(f) is the transmissibility, a_{seat}(f) is the acceleration on the seat, and a_{floor}(f) is the acceleration at the base of the seat at frequency f. If there is the same magnitude of acceleration at the floor and on the seat surface, then the transmissibility is unity i.e. there was no practical attenuation. Overall transmissibility can be expressed with a single SEAT value which is a ratio of overall RMS values of acceleration (or VDV) on the seat and floor.

$$SEAT_{r.m.s}\,\% = 100 \times \frac{r.m.s._{seat}}{r.m.s._{floor}}$$

$$SEAT_{vdv}\,\% = 100 \times \frac{VDV_{seat}}{VDV_{floor}}$$

SEAT % value shows the overall performance of a vehicle seat in terms of an indicator in regard to transmissibility of vibration. The further scope for understanding the problem with adequate details for effective engineering control has been kept out of the present research case study.

Result and Discussion

It was primarily observed that all the fifteen (15) dumpers had z or vertical axis as their dominant axis of seat vibration. Considering the magnitude of vibration along the dominant axis and respective duration of exposure per day,all their operators had indicated health risk when compared with Health Guidance Caution Zone (HGCZ) of ISO 2631-1:1997 (Table 3).

Table 3: Health risk assessment for vibration exposure using r.m.s acceleration

	Frequency weighted rms acceleration (ms^{-2})			rms acceleration multiplied by scale factor (ms^{-2})				
Equipment	a_{wx}	a_{wy}	a_{wz}	a_{wx}	a_{wy}	a_{wz}	**Duration of exposure (hours)**	**Health risk assessment as per HGCZ (ISO 2631-1 :1997)along dominant axis**
Dumper – 10	0.26	0.27	0.67	0.36	0.38	0.67	6.25	Indicated
Dumper – 11	0.30	0.32	0.66	0.42	0.45	0.66	6.25	Indicated
Dumper – 12	0.31	0.30	0.72	0.43	0.42	0.72	6.25	Indicated
Dumper – 13	0.48	0.49	0.78	0.67	0.69	0.78	4.40	Indicated
Dumper – 14	0.36	0.31	0.89	0.50	0.43	0.89	6.25	Indicated
Dumper – 15	0.47	0.48	0.73	0.66	0.67	0.73	4.77	Indicated
Dumper – 16	0.38	0.34	0.87	0.53	0.48	0.87	5.50	Indicated
Dumper – 17	0.33	0.39	0.82	0.46	0.55	0.82	6.25	Indicated
Dumper – 20	0.31	0.30	0.76	0.43	0.42	0.76	6.60	Indicated
Dumper – 23	0.24	0.27	0.62	0.34	0.38	0.62	6.23	Indicated
Dumper – 25	0.43	0.37	0.86	0.60	0.52	0.86	5.50	Indicated
Dumper – 28	0.31	0.39	0.85	0.43	0.55	0.85	5.50	Indicated
Dumper – 31	0.39	0.35	0.66	0.55	0.49	0.66	6.60	Indicated
Dumper – 32	0.33	0.37	0.71	0.46	0.52	0.71	6.23	Indicated
Dumper – 33	0.25	0.32	0.73	0.35	0.45	0.73	6.60	Indicated

Even though exposure duration is below five hours for Dumper -13 and 15, health risk has not come down. It is felt that even a minor increase in exposure duration in all the fifteen dumpers will pose high health risks. Summarily, the r.m.s acceleration values are visibly high enough to cause concern. These health risks mostly refer to the likelihood of developing low back pain (LBP) and other spinal disorders. Surprisingly the peak accelerations of the pneumatic-suspension seats were at least nine times compared to their r.m.s. accelerations. It seems that the advanced suspensions produced more bouncing effects compared to their rigid counterpart. Hence Crest Factors (CF) being greater than nine, vibration dose values for the pneumatic seats was further taken into account for additional evaluation as stipulated in ISO 2631-1:1997.The health risk was further affirmed by additional analysis using VDV values (Table 4). In the prevailing circumstances, none of the fifteen (15) operators were free from adverse health risk due to exposure to vibration during their daily work.

Table 4: Health risk assessment using VDV_T for equipment where CF> 9

Equipment	VDV_x	VDV_y	VDV_z	Duration of exposure (hours)	VDV_T along dominant axis	Health risk assessment as per HGCZ (ISO 2631-1:1997)
Dumper – 10	1.84	2.08	4.08	6.25	-	Indicated
Dumper – 11	2.35	2.65	5.20	6.25	11.63	Indicated
Dumper – 12	2.39	2.30	4.73	6.25	-	Indicated
Dumper – 13	3.12	3.48	5.41	4.40	-	Indicated
Dumper – 14	2.95	2.37	5.73	6.25	-	Indicated
Dumper – 15	2.96	3.07	4.62	4.77	-	Indicated
Dumper – 16	2.93	2.54	5.85	5.50	-	Indicated
Dumper – 17	2.57	3.51	6.06	6.25	13.55	Indicated
Dumper - 20	2.34	2.26	5.83	6.60	12.63	Indicated
Dumper - 23	1.79	2.23	5.80	6.23	12.56	Indicated
Dumper - 25	3.33	3.05	7.08	5.50	15.31	Indicated
Dumper - 28	2.34	2.40	5.60	5.50	-	Indicated
Dumper - 31	3.20	2.81	5.21	6.60	11.26	Indicated
Dumper - 32	2.43	2.62	4.33	6.23	-	Indicated
Dumper - 33	1.91	2.56	5.78	6.60	12.52	Indicated

Hence it becomes more imperative to know whether there is effective attenuation during transmission from seat base to seat surface. Accordingly the ratio of z/z′ was calculated for all these seats (Table 5). Overall, the vibration environment of these fifteen(15) seats was such that only two(2) of the seats were effective at reducing the vibration exposure slightly. Seats of dumper number 31 and dumper number 33 had SEAT values of 79 % and 78 % respectively using ratio of r.m.s. acceleration values (Table 5).

The SEAT values based on VDV for these two (2) seats were 79 % and 84 % respectively which were also lowest in the group. The other thirteen (13) seats had $SEAT_{r.m.s}$ values ranging from 92 to 125 % which were far from satisfactory.As observed at the time of study the dumper number 31 and 33 were incidentally hauling mostly on the horizontal road as indicated in the Table 1.

As evident from the results, moderate health risk was indicated for dumper operators due to vibration exposure. The geometric mean of SEAT factors of all the fifteen dumpers were observed to be 1.03 % and 1.05 % based on the frequency weighted r.m.s. acceleration values and Vibration Dose Values (VDV) respectively. The results obtained in this pilot study are consistent with other research literature available. The range of the SEAT values (0.78 to 1.31; Mean ±SD 1.02 ± 0.16) as obtained by Gunaselvam and Niekerk (2005) in their study on heavy person on bad gravel roadare close to our results (0.79 to 1.40; Mean ±SD 1.07 ± 0.18)[25]. These findings clearly depict that the seats installed in the dumpers are not efficient in reducing vibration or may have not been installed properly. They are definitely not being used as per procedures usually stipulated by reputed manufacturers. As echoed by Paddan and Griffin (2002) it is equally important to choose an appropriate vehicle seat for reducing the intensity of whole-body vibration. Additionally, incorrect adjustment of a seat suspension system can amplify vibration exposure[26]. As mentioned by Gunaselvam and Niekerk (2005) due to the frequency dependent properties of the suspension system, industrial seats should be selected properly for the specific vehicles or work places[25].As observed by Blood *et al.,* (2011) in their study higher quality vibration-damping seat technologies are more effective than the industry standard air suspension seats[27]. Being industry standard pneumatic seats provided in the dumpers under study could be one of the reasons for unsatisfactory performance of the seats.However, the haul road characteristics is a dynamic parameter which needs to be considered during interpretation of SEAT factor. As mentioned by Wang Fangfang *et al.,* (2016) not all pneumatic air suspension seats behave the same. Unpaved haul road condition in their study has contributed to the higher WBV as compared to the highway road segment[28]. Therefore, further in-depth evaluation of engineering designand seat ergonomics in these types of dumpers is desirable. The engineering control methods for whole body vibration are to reduce the transmission of vibration from source to receiver which includes, inter alia, improved vehicle suspension, cab suspension and suspended seats. Role of seat suspension are vital in attenuation of vibrations. It was clearly observed that the seat factor values are largely dependent on the seat-vehicle combination[29]. In our study, results illustrated that most of the pneumatic seats are actually amplifying the vibrations received from the body of the vehicle. Further, frequency analysis needs to be conducted for understanding the problem with adequate details for effective engineering control and utilizing the seats more optimally to yield better comfort for the dumper operators.

Table 5: Frequency weighted r.m.s. acceleration values in seat and floor channels

	Seat Channels (ms^{-2})			Floor Channel (ms^{-2})	SEAT Factor (z/z')
Equipment	**x-axis**	**y-axis**	**z-axis**	**z'- axis**	
Dumper – 10	0.26	0.27	0.67	0.73	0.92
Dumper – 11	0.30	0.32	0.66	0.71	0.93
Dumper – 12	0.31	0.30	0.72	0.64	1.13
Dumper – 13	0.48	0.49	0.78	0.66	1.18
Dumper – 14	0.36	0.31	0.89	0.81	1.10
Dumper – 15	0.47	0.48	0.73	0.65	1.12
Dumper – 16	0.38	0.34	0.87	0.72	1.21
Dumper – 17	0.33	0.39	0.82	0.83	0.99
Dumper - 20	0.31	0.30	0.76	0.65	1.17
Dumper - 23	0.24	0.27	0.62	0.56	1.11
Dumper - 25	0.43	0.37	0.86	0.69	1.25
Dumper - 28	0.31	0.39	0.85	0.77	1.10
Dumper - 31	0.39	0.35	0.66	0.84	0.79
Dumper - 32	0.33	0.37	0.71	0.75	0.95
Dumper - 33	0.25	0.32	0.73	0.93	0.78
				Mean±SD	1.05±0.14

Table 6: Vibration Dose Values (VDV) in seat and floor channels

	Seat Channels ($ms^{-1.75}$)			Floor Channel ($ms^{-1.75}$)	SEAT Factor (z/z’)
Equipment	**x-axis**	**y-axis**	**z-axis**	**z’- axis**	
Dumper – 10	1.84	2.08	4.08	4.73	0.86
Dumper – 11	2.35	2.65	5.20	5.55	0.94
Dumper – 12	2.39	2.30	4.73	4.44	1.07
Dumper – 13	3.12	3.48	5.41	4.56	1.19
Dumper – 14	2.95	2.37	5.73	5.35	1.07
Dumper – 15	2.96	3.07	4.62	4.17	1.11
Dumper – 16	2.93	2.54	5.85	4.89	1.20
Dumper – 17	2.57	3.51	6.06	6.45	0.94
Dumper - 20	2.34	2.26	5.83	4.70	1.24
Dumper - 23	1.79	2.23	5.80	4.19	1.38
Dumper - 25	3.33	3.05	7.08	5.06	1.40
Dumper - 28	2.34	2.40	5.60	5.17	1.08
Dumper - 31	3.20	2.81	5.21	6.62	0.79
Dumper - 32	2.43	2.62	4.33	4.91	0.88
Dumper - 33	1.91	2.56	5.78	6.85	0.84
				Mean±SD	1.07±0.18

Conclusion

It is vital to first realize the purpose of installing pneumatic seats in place of rigid seats previously used in the old dump trucks. Pneumatic seats with advanced features are supposed to provide seating comfort to the operators and must possess satisfactory dynamic characteristics. Attenuation of harmful vibration is among the primary requisites of a vehical seat in dynamic condition.The authors are first in India to have presented such study on SEAT factors of mining vehicles. From the pilot study it can be proclaimed that merely installing pneumatic seats perhaps is not sufficient to solve the problem. Installation alone should not be considered as an end of responsibility of mine owners. As this study unravels, the efficiency of the seats installed needs to be checked technically and ergonomically in the field condition. The seats need to be adjusted frequently considering the weight of the operator but the overall effect needs to be re-checked since vibration intensity has multifactor origin. Hence information in respect of the surface on which the vehicle is to be used, condition of the road, speed of the vehicle, driving style of the operator, weight and height of the operator, loading and unloading condition of the dump truck are required to resolve the issues holistically.

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Conflict of Interest

Authors state that there is no conflict of interest.

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