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PROPOSAL OF A NUMERICAL MODEL TO ASSESS THE WHOLE-BODY VIBRATION ON DRIVERS AND COMPARISON OF EVALUATION METHODOLOGIES OF DIFFERENT STANDARDS

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Abstract. *Recent changes in Brazilian legislation impose new requirements for assessing the level of occupational exposure to whole-body vibration (WBV). Since the publication of the Annex 1 to Regulatory Standard 09 (NR-09), the employer must assess or measure the square root of the sum of the squares (rms) (total value) of the frequency-weighted acceleration values (aren) and, also, the vibration dose value that represents the vector-sum over the three orthogonal axes (VDVR), defined in ISO 2631-1 (1997), over an eight-hour period.*
Due to these changes, Brazil adopted two exposure measures that are not used in European legislation or by the ACGIH (USA). According to European Directive 2002/44/EC, the exposure to vibration may be assessed using the highest root-mean-square value (A(8)), or the highest vibration dose value (VDV) of the frequency-weighted accelerations, over an eight-hour period.
Within this context, this study evaluates the daily exposure of a bus driver to whole-body vibration, using the Brazilian and the European exposure measures, and compares them with the exposure limit values. To this end, the dynamic model of the bus is subjected to different road profiles, using the Power Spectral Density parameters presented in ISO 8608 (1995). The evaluation of occupational exposure using the single-axis measure is compared with the assessment using the multi-axis approach.
The results show the importance of compliance with the legal requirements, and the need to apply the provisions of the Regulatory Standard 09 during the design stage of new equipment, so that their users are exposed to lower levels of vibration. In addition to the health risks, the workers exposure to vibration levels above the exposure limit values entails the payment of insalubrity premium, with considerable financial consequences for companies using that equipment and vehicles.

Keywords: *whole-body vibration, compliance, road roughness, numerical model, standards.*

1. INTRODUCTION

Exposure to vibration is a risk factor present in various sectors, such as transport, agriculture, forestry, and construction. According to Brazilian legislation, assessment of vibration levels to which workers are exposed is mandatory, in order to assess the control measures to minimize the risk and to determine if the worker is entitled to receive insalubrity premium (20% of the minimum wage). The Brazilian regulation uses different indicators from those used by the European Union and American Conference of Governmental Industrial Hygienists (ACGIH); however, it is not known yet if the use of those indicators leads to different results in terms of compliance with legal regulation.

According to the International Labour Organization (ILO), only 10-15% of workers around the world have access to occupational health services (Goelzer, 2014). Besides, reliable measurement, representative of the personal exposure of the worker, is usually expensive and requires a well-elaborated sampling plan; those resources, however, would be of better use if invested in effective measures to control the risk. In most cases, the difficulties encountered during the measurement process end up blocking the necessary preventive actions, especially in small and medium-size businesses.

According to the European Commission, 2006, when vibration magnitude and exposure time are measured, the uncertainty associated with the evaluation of the vibration level can mean that the calculated value can be as much as 20% above the true value to 40% below. Where one of them is estimated, the uncertainty can be much higher. Thus, even when a complicated process of measurement is made, with expensive equipment, the result can have high uncertainty.

The Brazilian legislation allows the use of a preliminary assessment, without measurement, to determine the control measures to minimize WBV exposure, and encourages the use of information provided by the manufacturer of the equipment. Thus, the efforts of the occupational health service are focused on controlling the risk, not in making series of not very useful measurements. It is also expected that the manufacturers, in order to provide an attractive product to their clients, improve the characteristics of their products with respect to WBV.

2. REGULATION

Vibrations are classified in Brazilian legislation as physical hazards that can characterize insalubrious work and, according to Regulatory Standard 15 (NR-15), the exposure to vibration levels above the daily exposure limits entails the perception of insalubrity premium. The old version of the Annex 8 to NR-15 made reference to the exposure limits established by ISO 2631-1; however, the most recent version of ISO 2631-1 did not set exposure limit values, only health guidance caution zones.

The lack of exposure limits caused the absence of exposure to WBV of most industrial hygiene programs in the last two decades. This fact led to a large number of lawsuits, in which experts witnesses used different criteria for evaluation of WBV exposure, generating considerable legal uncertainty.

The new version of Annex 8 and the recently edited Annex 1 to NR-9 give exposure limit values and exposure action values for two exposure measures: square root of the sum of the squares (rms)(total value) of the frequency-weighted acceleration values (*aren*) and vibration dose value that represents the vector-sum over the three orthogonal axes (*VDVR*). Those values are shown in Tab. 1.

Table 1. Exposure limit values and action values set by Brazilian legislation.

Measure	Daily exposure limit value	Daily exposure action value
aren	1.1 m/s^2	0.5 m/s^2
VDVR	21 $m/s^{1.75}$	9.1 $m/s^{1.75}$

The current version of Annex 8, unlike European legislation, does not use the highest RMS (root-mean-square) value (*A(8)*) or the highest vibration dose value (*VDV*) of the frequency-weighted accelerations over an eight-hour period in the assessment of the exposure to whole-body vibration. Despite using different measures for the evaluation of the exposure to WBV, Annex 1 to NR-9 and Annex 8 to NR-15 follow the international trend of using qualitative and semi-quantitative methods in the assessment of the occupational exposures. Table 2 shows a comparison among ACGIH, European Union, and Brazilian WBV references.

Table 2. Comparison among ACGIH, European Union, and Brazilian WBV references.

	ACGIH	European Union	Brazil
Reference	TLVs and BEIs	European Directive 2002/44/EC	Annex 1 to NR-09 and Annex 8 to NR-15
Measurement method	ISO 2631 (1985)	ISO 2631-1(1997)	NHO 09
Mandatory measurement	Not explicit	No	No
Measure	a_x, a_y, and a_z	*A(8)* or *VDV*	*aren* and *VDVR*

Assessment according to ACGIH evaluates acceleration for one-third octave band frequencies in the three directions of exposure (ACGIH, 2013). When the acceleration of any of the peaks of the spectra is equal or greater than the values presented by ACGIH, the Threshold Limit Value (TLV) is considered exceeded for that exposure time.

2.1 Definitions and correlations

Definition of the indexes of exposure whole body vibration is presented in the Occupational Hygiene Standard 09 (NHO 09), published by Fundacentro. The main indicators are presented below.

Instantaneous frequency-weighted acceleration [$a_j(t)$]: corresponds to $a_w(t)$ defined in ISO 2631-1 (1997); *j* represents direction axis *x*, *y* or *z*.

Root-mean-square single-axis acceleration value [am_j]: calculated according to Eq. (1), corresponds to a_w defined in ISO 2631-1 (1997).

$$am_j = \left\{ \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a_j^2(t) dt \right\}^{1/2} \tag{1}$$

Vibration total value [*amr*]: calculated according to Eq. (2), corresponds to a_v presented in ISO 2631-1 (1997).

$$amr = \sqrt{(f_x am_x)^2 + (f_y am_y)^2 + (f_z am_z)^2} \qquad (2)$$

In which f_x and f_y amount to 1.4 and f_z values 1.0.

Partial daily vibration exposure [$arep_i$]: calculated according to Eq. (3), corresponds to the total mean acceleration representative of the occupational exposure relative to the ith exposure component, occurred in a part of the working day, considering the three orthogonal axes.

$$arep_i = \frac{1}{s}\sum_{k=1}^{s} amr_{ik} \qquad (3)$$

Where amr_{ik} corresponds to the kth sample selected among the repetitions of the ith exposure component and s is the number of samples of the ith exposure component that have been measured.

Daily vibration exposure [*are*]: calculated according to Eq. (4),

$$are = \sqrt{\frac{1}{T}\sum_{i=1}^{m} n_i arep_i^2 T_i} \qquad (4)$$

Where T is the length of the working day, m is the number of exposure components in a working day, T_i is the duration of the ith exposure component and n_i is the number of repetitions of the ith exposure component.

Daily vibration exposure, expressed in terms of 8-h energy-equivalent frequency-weighted vibration total value [*aren*]: calculated according to Eq. (5),

$$aren = are\sqrt{\frac{T}{T_0}} \qquad (5)$$

Where T is the length of the working day and T_0 is 8 hours (or 480 minutes).

Vibration dose value [VDV_j]: calculated according to Eq. (6), in which j represents direction axis x, y or z.

$$VDV_j = \sqrt[4]{\int_0^t \left[a_j(t)\right]^4 dt} \qquad (6)$$

Vibration dose value [VDV_{ji}]: calculated according to Eq. (7).

$$VDV_{ji} = \left[\sum_{k=1}^{s} \left(VDV_{jik}\right)^4\right]^{1/4} \qquad (7)$$

Partial vibration dose value [$VDV\exp_{ji}$]: calculated according to Eq. (8).

$$VDV\exp_{ji} = f_j \times VDV_{ji} \times \left(\frac{T_{\exp}}{T_{amos}}\right)^{1/4} \qquad (8)$$

Vibration dose value [$VDV\exp_j$]: calculated according to Eq. (9), in which j represents direction axis x, y or z.

$$VDV\exp_j = \left[\sum_{i=1}^{m} \left(VDV\exp_{ji}\right)^4\right]^{1/4} \qquad (9)$$

Total vibration dose value [*VDVR*]: calculated according to Eq. (10).

$$VDVR = \left[\sum_j \left(VDV \exp_j \right)^4 \right]^{1/4} \tag{10}$$

3. VEHICLE EXCITATION

To compare the behavior of the different measures of WBV exposure, the response of a bus moving at a speed of 80 km/h on a road is simulated. The road roughness can be represented as a random process, and the bus model is that presented by Sekulic *et al.*, 2013.

3.1 Road profile generation

According to ISO 8608 (1995), road profiles can be described by the power spectral density of its vertical displacement, as Eq. (11).

$$G_d(n) = G_d(n_0) \cdot \left(\frac{n}{n_0} \right)^{-w} \tag{11}$$

In which n_0 is the reference spatial frequency (0.1 cycles/m), w is the exponent of the fitted PSD (a value of 2 is assumed, according to the standard) and $G_d(n_0)$ is the roughness coefficient. Roads can be classified into categories from A to H, according to their roughness coefficient, as shown in Tab. 3.

Table 3. Road classification.

Road class	Degree of roughness $G_d(n_0)$ 1) 10^{-6} m^3		
	Lower limit	Geometric mean	Upper limit
A	-	16	32
B	32	64	128
C	128	256	512
D	512	1024	2048
E	2048	4096	8192
F	8192	16384	32768
G	32768	65536	131072
H	131072	262144	-
1) n_0 = 0.1 cycles/m			

Source: adapted from ISO 8608, 1995.

ISO 8608 recommends the use of a spatial frequency range from 0.011 to 2.83 cycles/m, based on existing data in the literature; however, for special studies, with small distances and in off-road situations, the frequency range may be reduced.

Power spectral density can also be defined as a function of the frequency (*f*) in cycles per second (Hz). The relation between $G_d(n)$ and $G_d(f)$ is defined in Eq. (12), according to Davis and Thompson, 2001.

$$G_d(f) = \frac{1}{V} G_d\left(n = f/V \right) \tag{12}$$

Knowing the spectral density, the formulation presented by Sun, 2003, is used to compute temporal roughness excitation, according to Eq. (13). Such formulation is similar to that proposed by Shinozuka and Jan, 1972.

$$z(t) = \sum_{k=1}^{N} \left(2G_d(f_k) \cdot \Delta f \right)^{1/2} \cos\left(2\pi f_k t + \phi_k \right) \tag{13}$$

In which ϕ_k is an independent random variable with uniform distribution at the range $(0, 2\pi)$.

The profile obtained is assumed to correspond to the left wheel track; to find the right wheel track, the formulation presented by Sekulic *et al.*, 2013, is used, assuming also that there is a correlation between the left and the right track roughnesses, as can be seen in Eq. (14).

$$z_d(t)=\sum_{i=1}^{N}\left[\left(2\cdot G_{d_d d_e}(f_i)\cdot \Delta f\right)^{1/2}\cdot\cos(2\pi f_i t+\phi_i)+\left(2\cdot\left(G_d(f_i)-G_{d_d d_e}(f_i)\right)\cdot\Delta f\right)^{1/2}\cdot\cos(2\pi f_i t+\beta_i)\right] \quad (14)$$

In which β_i is an independent random variable with uniform distribution at the range $(0,2\pi)$ and $G_{d_d d_e}(f_i)$ is the cross-spectral density function given by Eq. (15).

$$G_{d_d d_e}(f_i)=\gamma_i G_d(f_i) \quad (15)$$

Where γ_i is given by Eq. (16) and ν_l amounts to 0.2 cycles/m, according to Sekulic *et al.*, 2013, and Sayers, 1998.

$$\gamma_i=\frac{\nu_l^2}{\nu_l^2+\left(\frac{f}{V}\right)^2} \quad (16)$$

To analyze the effect of a shock, a class I speed bump (length of 1.5 m and height of 0.08 m, according to Resolution 35/98 of National Traffic Council – CONTRAN) is introduced in the road profile. The bus goes over the speed bump at a speed of 30 km/h.

3.2 Vehicle model

This article adopts the model used by Sekulic *et al.*, 2013, based on the intercity bus IK-301. The main parameters of this bus model are shown in Tab. 4.

Table 4. Main parameters of the bus model.

Axes	2
Distance from the front axle to the bus center of gravity	3.61 m
Distance from the rear axle to the bus center of gravity	2.04 m
Wheelbase	5.65 m
Elastic-suspended mass of the fully loaded bus	15,890 kg

The adopted assumptions for the model are, according to Sekulic *et al.*, 2013:
_ the bus is symmetrical about the longitudinal center of gravity axis (*x*-axis);
_ all possible motions of concentrated masses around the position of stationary equilibrium are small;
_ the bus body, front, and rear axles are rigid bodies;
_ the bus engine is included in the bus body so that engine oscillatory excitation has not been taken into account;
_ characteristics of all elastic and damping elements are linear;
_ bus wheels are in permanent contact with the road surface;
_ the bus is moving along a straight line with constant speed.

Also, it is assumed that the model does not consider the effects of stiffness and damping of the driver-seat system relative to longitudinal and transverse axes.

Considering the assumption of rigid bodies, the longitudinal and the lateral acceleration are calculated according to Eq. (17), adapted from Awrejcewicz, 2012. The vertical acceleration is obtained through the equations of motion presented by Sekulic *et al.*, 2013.

$$\vec{a}_M=\vec{a}_{CG}+\vec{\alpha}\times\vec{r}_{M/CG}+\vec{\omega}\times\left(\vec{\omega}\times\vec{r}_{M/CG}\right) \quad (17)$$

In Eq. (17), $\vec{a}_{CG}$, $\vec{\alpha}$ and $\vec{\omega}$ are the linear acceleration, the angular acceleration and the angular velocity of the center of gravity, respectively, and $\vec{r}_{M/CG}$ is the position of driver's workstation to the center of gravity of the bus. According to Blundell and Harty, 2004, a vehicle traveling in a straight line has a yaw velocity equal to zero and a centripetal acceleration equal to zero.

Sekulic *et al.*, 2013, do not inform the vertical distance from the driver seat to the center of gravity of the bus. This information is unnecessary when only the vertical acceleration transmitted to the driver is assessed, which occurs when the highest RMS value and VDV occur on the vertical axis. However, when the lateral and the longitudinal acceleration are evaluated, this parameter is required. To estimate such parameter, data on similar national bus models were used, and a distance of 60 cm from the driver's seat to the center of gravity is adopted.

4. ANALYSIS OF SIMULATION RESULTS

Assessment of exposure to WBV is carried out according to ISO 2631-1 (1997). The note to item 5.5 points out that for stationary random signals, the measurement accuracy depends on the filter bandwidth and measurement duration (ISO 2631-1, 1997). It also notes that to obtain a measurement error of less than 3 dB at a confidence level of 90%, minimum measurement duration of 227 s is required for a lower limiting frequency of 0.5 Hz, when the analysis is done with a one-third octave bandwidth. Thus, a simulation time of 240 s is adopted.

It is considered, for comparison purposes, that only one road class is covered in a working day and that $T = T_0$. Tables 5 and 6 present the results for acceleration (m/s^2) and VDV (m/s$^{1.75}$). The results for the *x*- and *y*- directions are not multiplied by the f_x and f_y factor.

Table 5. Comparison among am_x, am_y, am_z and am_r for different road classes, with and without a speed bump.

Class	No speed bump				With speed bump			
	am_x	am_y	am_z	*amr*	am_x	am_y	am_z	*aren*
A	0.007	0.031	0.185	0.190	0.009	0.032	0.240	0.245
B	0.014	0.062	0.376	0.387	0.015	0.061	0.399	0.409
C	0.027	0.122	0.733	0.754	0.029	0.121	0.771	0.790
D	0.060	0.243	1.555	1.595	0.054	0.253	1.462	1.506
E	0.110	0.488	2.934	3.016	0.113	0.504	2.954	3.045

Table 6. Comparison among VDV_x, VDV_y, VDV_z and *VDVR* for different road classes, with and without a speed bump.

Class	No speed bump				With speed bump			
	VDV_x	VDV_y	VDV_z	*VDVR*	VDV_x	VDV_y	VDV_z	*VDVR*
A	0.038	0.163	0.969	0.970	0.121	0.166	3.341	3.341
B	0.073	0.306	1.878	1.879	0.125	0.313	3.467	3.467
C	0.134	0.626	3.681	3.684	0.148	0.616	4.005	4.007
D	0.295	1.194	7.787	7.791	0.285	1.327	7.651	7.658
E	0.537	2.508	14.724	14.736	0.608	2.613	15.49	15.50

Table 7 presents the crest factors (CF) obtained in the different roads in the *x*, *y* and *z* axes. This result is important, considering the warning given by ACGIH, 2013, that when the CF is greater than 6, the TLV may underestimate the effects of the exposure.

Table 7. Comparison among CF_x, CF_y and CF_z for different road classes, with and without a speed bump.

Class	No speed bump			With speed bump		
	CF_x	CF_y	CF_z	CF_x	CF_y	CF_z
A	3.32	3.58	3.09	18.29	3.79	21.43
B	3.06	3.19	2.95	11.89	3.37	13.50
C	2.68	3.36	3.76	4.95	3.33	5.91
D	2.44	2.81	2.85	3.01	3.43	3.81
E	2.63	3.33	3.76	3.28	3.53	3.10

The results for class B roads are comparable to those presented by Bovenzi, 2010, as corresponding to the exposure of a bus driver in public transport. In that study, the acceleration magnitude of WBV measured in the *x*-, *y*- and *z*-directions on the seat of some industrial machines and transport vehicles is presented. However, Bovenzi, 2010, and most of the studies on exposure to WBV do not provide much information on the characteristics of the roads and the vehicles used, which makes difficult the comparison of results.

Tables 8 and 9 present the summary of the results and the verification of their compliance with legal requirements of ACGIH, European Union, and Brazil. In the case of the European Union, it is not considered the possibility of choice between A(8) and VDV, allowed in European Directive 2002/44/EC; when one of the parameters is exceeded, the exposure limit is considered exceeded.

Table 8. Summary of results in the section of a road with a speed bump.

	ACGIH		European Union				Brazil (NR-09/NR-15)			
Class	Exposure limit exceeded	Note	A(8)	*VDV*	Action level exceeded	Exposure limit exceeded	*aren*	*VDVR*	Action level exceeded	Exposure limit exceeded
A	No		0.240	3.341	No	No	0.245	3.341	No	No
B	No		0.399	3.467	No	No	0.409	3.467	No	No
C	Yes	1.6-2Hz, *z* axis	0.771	4.005	Yes	No	0.790	4.007	Yes	No
D	Yes	1-3.5Hz, *z* axis	1.462	7.651	Yes	Yes	1.506	7.658	Yes	Yes
E	Yes	1-5Hz, *z* axis	2.954	15.49	Yes	Yes	3.045	15.50	Yes	Yes

Table 9. Summary of results in the section of a road without the speed bump.

	ACGIH		European Union				Brazil (NR-09/NR-15)			
Class	Exposure limit exceeded	Note	A(8)	*VDV*	Action level exceeded	Exposure limit exceeded	*aren*	*VDVR*	Action level exceeded	Exposure limit exceeded
A	No		0.185	0.969	No	No	0.190	0.970	No	No
B	No		0.376	1.878	No	No	0.387	1.879	No	No
C	Yes	1.6-2Hz, *z* axis	0.733	3.681	Yes	No	0.754	3.684	Yes	No
D	Yes	1-3.5Hz, *z* axis	1.555	7.787	Yes	Yes	1.595	7.791	Yes	Yes
E	Yes	1-5Hz, *z* axis	2.934	14.724	Yes	Yes	3.016	14.736	Yes	Yes

The use of the different legal criteria led to the same results in terms of compliance with the respective legal requirements, which happens mostly because the bus movement has one clear dominant axis, and vector-sum is not considerably higher than the vibration in that axis. The only case in which the different criteria led to different results was the bus moving over a class C road: the ACGIH criteria indicates that the exposure limit is exceeded, while the European Union and the Brazilian criteria indicate that the action level is exceeded, but not the exposure limit.

The same does not occur in activities like mining, construction and forestry when usually the vibration in two or more axis is comparable. Table 10 presents the results obtained by Eger *et al.*, 2013, which analyses the exposure of large and small load-haul-dump (LHD) operators, and the results reported by Pazooki *et al*., 2012, for an operator of a forestry skidder.

Table 10. Results reported by Eger *et al.*, 2013, and Pazooki *et al.*, 2012.

	am_x	am_y	am_z	*aren*	VDV_x	VDV_y	VDV_z	*VDVR*
Large LHD	0.83	0.56	0.81	1.62	9.53	7.10	12.30	15.93
Small LHD	0.79	0.56	1.01	1.69	8.17	6.17	13.12	15.12
Forestry skidder	0.89	1.07	0.65	2.05	-	-	-	-

The exposures presented in Tab. 10 do not exceed the exposure limit set by the European Union; however, the vector-sum exceeds the exposure limit set by Brazilian legislation.

5. CONCLUSIONS

This paper evaluated the daily exposure of a bus driver to WBV, using the ACGIH, European Union, and Brazil standards. To this end, a numerical model was proposed, in which the dynamic model of the bus was subjected to different road profiles, using the PSD parameters given in ISO 8608 (1995). The evaluation of occupational exposure using these different standards was carried out and compared.

The use of different legal criteria, when the exposure has one dominant vibration axis, does not led to different results in terms of compliance with regulation. However, when there is no dominant axis, the Brazilian legislation is more protective.

It was observed, during this study, the absence of information from Brazilian manufacturers regarding the characteristics that can influence the vibration exposure of operators and drivers. The encouragement of the recently published Annex 1 to NR-09 to the use of manufacturer data and the large number of lawsuits related to vibration exposure, besides the desire to prevent the payment of insalubrity premium to a large number of workers, make research on WBV a competitive edge for manufacturers.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

ACGIH, 2013. *TLVs e BEIs – Baseados na Documentação dos Limites de Exposição Ocupacional (TLVs) para Substâncias Químicas e Agentes Físicos & Índices Biológicos de Exposição (BEIs)*. Brazilian Association of Industrial Hygienists.

Awrejcewicz, J., 2012. *Classical Mechanics: Kinematics and Statics*. Springer, New York.

Bovenzi, M., 2010. "A Longitudinal Study of Low Back Pain and Daily Vibration Exposure in Professional Drivers". *Industrial Health*, vol 48, p. 584 – 595.

Brazil, 2012. "Norma de Higiene Ocupacional 09". Fundação Jorge Duprat Figueiredo de Segurança e Medicina do Trabalho (Fundacentro).

Brazil, 2014. *Norma Regulamentadora 9 – Programa de Prevenção de Riscos Ambientais*. Ministério do Trabalho e Emprego.

Brazil, 2014. *Norma Regulamentadora 15 – Atividades e Operações Insalubres*. Ministério do Trabalho e Emprego.

Brazil, 1998. *Resolução 35/98*. Conselho Nacional de Trânsito – CONTRAN.

Blundell, M. and Harty, D., 2004. *Multibody Systems Approach to Vehicle Dynamics*. Elsevier, 1st edition.

Davis, B.R. and Thompson, A.G., 2001. "Power Spectral Density of Road Profiles". *Vehicle System Dynamics*, Vol. 35, No. 6, pp. 409-415.

Eger, T., Kociolek, A. and Dickey, J., 2013. "Comparing Health Risks to Load-Haul-Dump Vehicle Operators Exposed to Whole-Body Vibration Using EU Directive 2002/44EC, ISO 2631-1 and ISO 2631-5". *Minerals*, Vol. 3, 16-35.

European Commission, 2006. "Guide to Good Practice on Whole-Body Vibration - Non-binding guide to good practice with a view to implementation of Directive 2002/44/EC on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibrations)". 07 Sep. 2014. <http://resource.isvr.soton.ac.uk/HRV/VIBGUIDE/2008_11_08%20WBV_Good_practice_Guide%20v6.7h%20English.pdf>

Goelzer, B., 2014. "Higiene Ocupacional: Tendências Internacionais." 07 Sep. 2014. <http://www.fundacentro.gov.br/Arquivos/sis/EventoPortal/AnexoPalestraEvento/BGoelzer%20Palestra%2012%20Fev.pdf>

Griffin, M.J., 1990. *Handbook of Human Vibration*. Elsevier Academic Press, London.

ISO 2631-1, 1997. Mechanical vibration and shock-evaluation of human exposure to whole-body vibration. 2nd ed.

ISO 8608, 1995: Mechanical vibration – Road surface profiles – Reporting of measured data.

Pazooki, A., Rakheja, S. and Cao, D., 2012. "Modeling and validation of off-road vehicle ride dynamics". Mechanical Systems and Signal Processing, Vol. 28, p. 679-695.

Sayers, M.W., 1998. "Dynamic terrain inputs to predict structural integrity of ground vehicles". The University of Michigan Transportation Research Institute, Michigan. 27 Sep. 2014. <http://deepblue.lib.umich.edu/bitstream/handle/2027.42/769/77008.0001.001.pdf?sequence=2&isAllowed=y>

Sekulic, D., Dedovic, V., Rusov, S., Salinic, S. and Obradovic, A., 2013. "Analysis of vibration effects on the comfort of intercity bus users by oscillatory model with ten degrees of freedom". *Applied Mathematical Modelling*, vol 37, p. 8629 – 8644.

Shinozuka, M.; Jan, C-M., 1972. "Digital simulation of random processes and its applications". *Journal of Sound and Vibration*, vol. 25-1, p. 111-128.

Sun, L., 2003. "Simulation of pavement roughness and IRI based on power spectral density". *Mathematics and Computers in Simulation*, vol. 61, p. 77-88.

8. RESPONSIBILITY NOTICE

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