Vibrations Transmitted to The Human Body Under the Dynamic Action of Surfaces and Mechanical Contact Points with Impact on Human Health

George NICOLAE
Institute of Solid Mechanics of the Romanian Academy, C-tin Mille, no. 15, Bucharest, Romania, nicolaegeorge91@yahoo.it

Cristina Marilena NIȚU
Institute of Solid Mechanics of the Romanian Academy, C-tin Mille, no. 15, Bucharest, Romania, cristina.nitu@imsar.ro

Polidor BRATU
Institute of Solid Mechanics of the Romanian Academy, C-tin Mille, no. 15, Bucharest, Romania, ICECON SA, Bucharest, Şos. Pantelimon, 266, sector 2, Romania, bratupolidor@yahoo.com

Mihaiela ILIESCU
Institute of Solid Mechanics of the Romanian Academy, C-tin Mille, no. 15, Bucharest, Romania, iliescumihaiela7@gmail.com

Emilia FURDUI-LUNGUȚ *
Titu Maiorescu University, CF2 Hospital, Bucharest, Romania, lungut.emilia@yahoo.com

Marina DOGARU
Technical University of Civil Engineering of Bucharest, Bucharest, Romania, marina.dogaru78@gmail.com

* Author to whom correspondence should be addressed

Abstract: - Research conducted over the last ten years, since 2014, has highlighted the effect of vibrations transmitted to the human body in direct contact with the surfaces and contact points of construction machinery. Thus, depending on the spectral composition of the vibrations, the exposure duration, and the transmission points of the wave vibration motions on the human body, criteria, acceptability levels, and effective analyses have been synthesized from the perspective of the type of construction machinery. In this context, the psychosensory and pathophysiological effects of the vibrations transmitted to the human body at the control post of the construction machinery while working on road and highway technologies in Romania were studied. This article outlines the specific requirements for vibration protection, as well as the vibration levels transmitted to the human body through the seat, hand-arm, and neck-head in the work cabin. Thus, the experimental values of the measured vibrations are provided.

Keywords: - transmitted vibrations, psychosensory effects, vibration protection, regulatory requirements for vibration.

1. INTRODUCTION

The effects of vibrations transmitted to the human body have been studied for 115 types of construction machinery used in earthworks for roads and highways in Romania over the past decade. The tests carried out yielded remarkable results regarding the spectral composition, exposure duration, intensity, and severity of vibrations, with an impact on both the people driving the machinery and the natural or built environment in the vicinity of the working position.

This article presents the parametric values of the transmitted vibrations and their harmful effects.

Based on the results obtained, limit levels of severity for the vibrations transmitted to the human body were set. Thus, regulatory documents on

construction approved by the competent authority have been elaborated to ensure the assessment procedure for vibrating machines at the technical inspection stage.

The experimental results are presented in tables grouped by the type of construction machinery [1-4].

2. SPECIFIC REQUIREMENTS ON VIBRATION PROTECTION

2.1. Harmful action of vibrations

Exceeding the allowable level of vibrations in terms of intensity and duration of exposure causes organic disturbances with physiological and psychosensory effects.

Vibrations are characterized by their frequency, amplitude, and acceleration. The relationship between amplitude and frequency, as well as their effects on human perception, led to the distribution of curves, as shown in Figure 1.

The prolonged action of vibrations on the human body would lead to manifestations of nausea, loss of appetite, vomiting, headache, pulse changes, and vibration disease at 30 - 250 Hz.

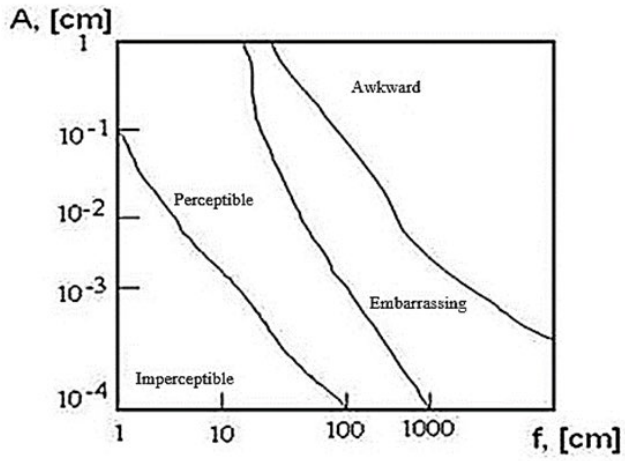

Figure 1. Perception effects (by Woodson, W)

Harmful vibrations are classified from the point of view of amplitude and frequency as follows:

a) in vibrations with a frequency greater than 15 Hz and amplitudes up to 0.02 mm, the decisive influence is that of the speed of vibrations;

b) in vibrations with high amplitudes and low frequencies, a decisive role is that by the acceleration of vibrations.

The perception of vibrations by frequency leads to the following classification:

a) vibrations below 15 Hz specific to vehicles: cars 1.5 ÷2 Hz, trucks 2÷4 Hz, trains 3÷8Hz; when prolonged exposure is done, there could result paravertebral pain, digestive and urinary tract disorders;

b) vibrations with frequencies between 15 and 40 Hz with high amplitudes (breaking hammers, fast loading and unloading equipment).

Specific injuries are osteoarticular, tendons, and muscle types as follows [5,6,7]:

a) vibrations with frequencies between 40÷300Hz, in steel, mining, and metallurgical machinery; a burning sensation occurs in the limbs, and the sensitivity of the fingers decreases;

b) vibrations with frequencies above 300 Hz, specific to certain machine tools such as grinding, milling, lapping, and polishing, can cause trophic and sensory disorders of the hands.

The effects of vibration on the human body are listed in Table 1.

Table 1. The effects of vibrations on the human body

Current no.	Physiological process	Effect	Vibrations	
			Frequency (Hz)	Amplitude
1	Sweat control	decreases	3.5÷6.0	1.9
			4.0÷8.0	0.35÷1.5
2	Body temperature	increases	40.0	0.16
			70.0	0.08
3	Hand tremor	increases	20.0	0.035÷0.089
			25.0	0.089÷0.140
			30÷300	0.05÷0.51
			1000	0.02
4	Fixed gaze	decreases	15.0	0.18
			25.0	0.089÷0.140
			35.0	0.08÷0.13

2.2. Effects of vibrations on the human body

In both self-propelled and stationary machines, the vibrations transmitted to the workstation are perceived by the body (especially by the parts of the body in direct contact with the components of machinery that are in vibratory motion), as wave processes with continuous transmission.

The mechanical vibrations produced by construction machinery are transmitted to the human body in the following ways:

- to the whole body – through the common surface with contact in the human-machinery relationship, when the person is standing or sitting;
- to parts of the body (hand-arm, pelvis, internal organs, head)

Mechanical vibrations transmitted to the human body have complex, harmful actions, affecting health through pathophysiological effects. The most

important effects produced by the action of vibrations are physiological, mechanical, and thermal (the first two being preponderant).

2.2.1. Physiological and pathological effects of vibrations on the human body

As a result of the human body's exposure to vibrations, functional and organic disorders could appear, such as [5,8,9]:

- stimulation of the nervous system and hormonal activity that causes changes in some metabolic processes;
- appearance of tactile, thermal, and painful sensitivity disorders;
- the appearance of states of fatigue and drowsiness manifested by decreased attention and visual acuity, leading to a reduction in work capacity;
- the appearance of emotional states, fear, or anxiety;
- appearance of chest pain, epigastric pain, followed by nausea, loss of appetite, vomiting, and headache;
- increased pulse and blood pressure, changes in the function of the respiratory system;
- the appearance of vascular disorders accompanied by excessive cooling of the limb extremities that encounter the vibrating parts of the machinery (whitening of the fingers leading to lack of sensitivity, to the appearance of a dead finger);
- causing osteoarticular and tendon injuries.

a) The mechanical influence of vibrations on the human body

Depending on the mode of application and the size of the vibrations, kinematic parameters (displacement, speed, and acceleration) and neuromuscular and sensory disorders appear, such as:

- visual acuity disorders, related to reading the units shown by the devices on the control panel of the machinery or to the inaccuracies of performing operations in the technological processes (posting the panels at the assembly site, carrying out earthworks at certain levels that require concentrated effort);
- functional disorders of the upper and lower limbs, which are not dangerous from a health perspective, but lead to the loss of the ability to perform fine and precision commands.

These disorders can be reduced by changing the vibration parameters (frequency, amplitude) and the exposure time. Otherwise, there would be a decrease in the level of the range of technological parameters.

Among the most important mechanical injuries caused by vibrations are:

- bone fractures because of vibrations with both high amplitude and high acceleration, such as when driving on unpaved roads and at relatively high speeds;
- injury to the innermost layers of the intestines – when operating vibrating machinery without special protection for the workstation, where the vibration acceleration exceeds 6g for frequencies higher than 25 Hz;
- brain and lung damage, cardiac damage caused by vibrations with a frequency higher than 30 Hz, and high vibration speed, when operating vibrating machinery and those that produce shocks;
- soft tissue tears, tendon stretching, and joint issues – when operating cars with levers or steering wheels that are not protected against vibrations or using mechanical tools that employ vibrations or vibro-percussion; mechanical disorders such as white finger syndrome could also appear.

b) The physiological influence of vibrations on the human body

By the mechanical action of vibrations on the human body, sensory receptors located in the skin or in other parts of the body are stimulated, and certain projection areas of the cortex can be directly excited. Stimulating the nervous system and hormonal activity could determine changes in the metabolic processes of assimilation, muscle activity (during physical work), and the activity of the reproductive organs. For certain vibration regimes, changes in breathing, cardiac activity, and disturbances in peripheral blood flow occur.

c) Subjective responses to vibration exposures

For the person working under the influence of the transmission of sensations on their own body, the subjective responses are:

- perception;
- the feeling of discomfort;
-fear;
-pain.

The following factors simultaneously influence these subjective responses to vibration exposure:

- vibration parameters; - the way of transmitting vibrations to the human body;
- the position of the body while exposed to vibrations;
- duration of exposure to vibrations.

To evaluate the subjective responses to the vibration regime transmitted to the human body, three criteria were adopted:

- the perception threshold;
- the threshold of feeling unpleasant;
- tolerance limit (acceptability threshold).

The variation curves of the average maximum acceleration as a function of frequency and perception level are shown in Figure 2.

The curves were drawn based on the experimental results obtained from exposure to vibrations for 5–20

min. Prolonged exposure to a vibration regime above the perception limit becomes irritating and tiring. In the case of short-term exposures (less than 5 min), in the frequency range between 1...5 Hz, people were subjected to a discreetly valid vibration regime, up to the limit of tolerability assessed individually. The hatched surfaces have a width equal to the mean square deviation determined for each sample group and are positioned on both sides of the mean value [10, 11, 12, 13].

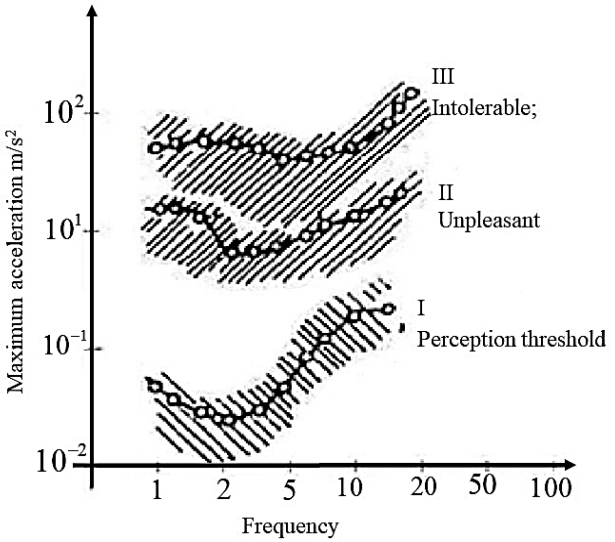

Figure 2. Evaluation of the subjective responses by people exposed to vibrations

d) Evaluation of the vibration effects on the human body

To evaluate the relationship between humans and machinery as accurately as possible and quantify exposure to vibrations, research has been conducted on the health of various organs and systems that are likely to be affected. Thus, for individuals exposed to a specific vibration regime, prophylactic determinations and evaluations of physiological changes that may lead to vibration-related diseases are conducted.

Functional investigation tests refer to the aspects mentioned below.

- Determination of vibration sensitivity by keeping a set of parameters constant and varying a single parameter. In the case of workers exposed to the vibration regime, an increase in the sensitivity threshold has been observed by keeping the frequency constant and increasing only the amplitude or by maintaining a constant amplitude and varying the frequency;

- Determination of the skin temperature at the level of the fingers using sensitive thermocouples that provide simultaneous information. It was found that the temperature dropped by more than 10 ºC when compared with the situation of non-exposure to vibrations;

- Capillaroscopy, which highlights the simultaneous presence of normal and spastic capillaries at the nail level;

- Exploration of neuromuscular excitability.

As a result of complex research, Dieckmann established specific criteria regarding how the human body perceives vibrations, physiological and vegetative changes, subjective sensations, and work ability.

Experiments were conducted for harmonic vibrations in the vertical or horizontal direction, considering both the vibration amplitude and frequency. This is because, for the same disturbing frequency, different parts of the human body, which are elastically connected to each other, exhibit different amplitudes.

A vibration stress coefficient is defined to consider the simultaneous influence of frequency and amplitude as follows:

- $k = x_0 \cdot f^2$ - for frequency values < 5Hz;

- $k = 5 \cdot x_0 \cdot f^2$ - for frequency values of 5...40 Hz;

- $k = 200 \cdot x_0 \cdot f^2$ - for frequency values of 40...100 Hz.

$$k = a_{ef} \frac{\alpha}{\left[1+\left(\frac{f}{f_0}\right)^2\right]^{1/2}};$$

$$k = v_{ef} \frac{\beta}{\left[1+\left(\frac{f}{f_0}\right)^2\right]^{1/2}};$$

$$k = x_{ef} \frac{\gamma}{\left[1+\left(\frac{f}{f_0}\right)^2\right]^{1/2}};$$

where: a_{ef} - the efficacy acceleration, mm/s²;

v_{ef} - the efficacy speed, mm/s;

x_{ef} - the efficacy displacement, mm;

f - frequency of vibration, Hz;

$$\alpha = 12,5 s^2 / mm;$$

$$\beta = 0,112 s^2 / mm;$$

$$\gamma = 0,50 s^2 / mm.$$

Table 2 presents the value levels for the vibration stress coefficient and psycho-sensorial sensitivity, with their effects evaluated by the person at the workplace.

Table 2. The effects of vibrations on the human body

Vibration stress coefficient, k	Sensitivity	Work evaluation
0.1	Not perceptible	Not embarrassing
0.1...0.3	Barely perceptible, well bearable	Not embarrassing
0.3...1	Perceptible after a few hours, a little unpleasant, bearable	Low embarrassing
1...3	Good	Embarrassing, but still possible
3...10	Unpleasant, after an hour it becomes unbearable	High embarrassing, but still possible
10...30	Very unpleasant	Not so possible
30...100	Unpleasant to the highest degree, and after 1 minute the activity must be interrupted	Impossible
Over 100	Unbearable	Impossible

Because the experimental results are uncertain in the frequency range of 5–20 Hz, it is necessary to draw representative diagrams for the type of machinery used in the defined technological process.

To assess the harmfulness and perception limit, based on the results of the research carried out by several researchers, I. J. Soliman (in the paper "Criteria Permissible Levels of Industrial Vibration with Regard to Their Effect on Human Beings and Buildings") established the variation curves for displacement, velocity, acceleration, and acceleration of the second order, depending on the frequency. On this basis, reiterations and research on case studies have been conducted [14, 15, 16].

3. EXPERIMENTAL RESULTS ON VIBRATIONS TRANSMITTED TO THE HUMAN BODY

Between 2014 and 2024, vibration measurements were performed on construction machinery working on road construction sites in Romania.

Thus, the vibrations transmitted to the human body at the steering wheel, seat, and floor were measured in the work cabin while the technological work process was performed. The results are summarized in Table 3. The measuring equipment used was the Brüel & Kjaer series from 2010 to 2013, purchased by ICECON Bucharest.

By analyzing the results in Table 3, further strategies for safety regulations regarding the person operating the construction machinery in the technological process can be developed [17].

Table 3. Test results

Crt No.	Machinery	Max level vibration/frequency. 1/3 oct. m/s^2 / Hz			Observation
		Driving wheel	chair	floor	
Excavators (bucket, rotor, scrapers, squeegees)					
1	P 802 (PROMEX)	0.6839/31,5	0.2213 / 31,5	0.2399 / 50	can work over 4 h
2	P 851 HyEl (PROMEX)	0.6761/63	0.1413 / 63	0.4121 / 63	can work over 4 h
3	S 1204 HyEl (PROMEX)	-	0.2630 / 63	1.6596 / 63	can work over 8 h
4	S 1203 (PROMEX)	-	0.1216 / 31,5	0.1884 / 31	can work over 8 h
Backhoe					
1	Backhoe CATERPILLAR type 428 D	0.5188/ 63	0.0871 / 63	0.3126 / 63	can work over 8 h
2	Backhoe FIAT -HITACHI type FB 90 / 2 – 4PT	0.1972 / 31,5	0.2723 / 25	0.1698 / 25	can work over 8 h
3	Excavator–Loader, model BOREX, type 2101	3.8019 / 50	1.1092 / 50	1.5668 / 50	can work over 2 h
4	Front loader, multifunctional model COMELF, type 50.25	2.5119 / 80	0.2692 / 50	1.8621 / 80	can work over 4 h

5	Backhoe FIAT – HITACHI , type FB 100 – 4PT/A	0.6998 / 40	0.1303 / 64	0.1365 / 63	can work over 8 h
6	Hidromek TR HMK type 102B	0.2213/315	0.0442 / 16	0.1429 / 63	can work over 8 h
7	JCB, type 2CX Streetmaster	0.5821/63	0.1549 / 31,5	0.5754 / 63	can work over 8 h
8	KOMATSU, type WB 93R - 2	0.3508 / 80	0.0447 / 16	0.3311 / 63	can work over 8 h
Front loader (tires, tracks, skid)					
1	Multifunctional compact machinery, model ROBOT, type170, JCB	.5433/400	0.1202 / 80	0,3890 / 80	can work over 8 h
2	Front loader GEHL, model SL 4625	0.7499/400	0.2018 / 80	.1380 / 80	can work over 8 h
3	Front loader IF 130 (NICOLINA)	1.4289 / 20	1.4962 / 20	-	can work over 8 h
4	model JCB, type 407B ZX	0.5012 / 63	0.0525 / 16	0.1462 / 50	can work over 8 h
5	model KOMATSU, type WA 270 - 3	0.3428/80	0.0624 / 25	0.0832 / 80	can work over 8 h
6	Forklift containers, type MO-G 36-4CH-5BI (forks)	0.2 / 250	0.022 / 63	0.192 / 80	can work over 8 h
Compactors					
1	Vibratory compaction roller, type W 554 (Vibromax)	-	-	-	
2	Vibratory compaction roller, type BW 141 AD-2 (BOMAG)	3.1623/31,5	0.9333 / 40	2.0893 / 31,5	can work over 2.5 h
3	Vibratory compaction roller, type BW 211 D-3 (BOMAG)	1.7989/31,5	0.7762 / 31,5	0.4519 / 80	can work over 2.5 h
4	Tire compactor roller, model DYNAPAC, type CP 201	5.2481/400	0.2317 / 31,5	0.2265 / 80	can work over 8 h
5	Vibratory compaction roller, model VIBROMAX, tip W 1601	2.3988/16	2.4266 / 16	2.5119 / 16	can work a maximum of 1 h
Pickaxes, Demolition hammers, or punches					
1	Portable power demolition tool, model SPIT, type 490 (PRAKT)	50.6991/63 -		-	can work for less than 30 min
2	Portable power demolition tool, model SPIT, type 331 (PRAKT)	62.3735/63	-	-	can work for less than 30 min
Asphalt mixing stations					Stationary - Mobile
1	IMA E (NICOLINA)	-	-	-	Stationary
2	Model NICOLINA - MARINI, type 80 – 90	-	-	-	Stationary
Vibratory plates, vibratory rammer					
1	Compaction vibratory plate, model AMMANN, type AVH 6020	0,9226/50	-	-	can work less over 8 h
2	Unidirectional compaction vibratory plate, model BOMAG, type BP 18/45 D -2	20.6538/40	-	-	can work for less than 30 min
3	Compaction vibratory hammer, model: SL 2R (VIBROMAX)	16.5959/50	-	-	can work for less than 30 min
4	Vibratory plate – type VD 450/22	17.3780/40	-	-	can work for less than 30 min
5	Vibratory plate RAVI, model: RRP 21 DY	16.4059/80	-	-	can work for less than 30 min

4. CONCLUSIONS

This study addresses a crucial topic related to human health, specifically the vibrations transmitted to the human body by construction machinery operating on construction sites in Romania.

Vibration evaluation was performed by measuring directly at the control station of the machinery and in the surrounding environment. This is how the pollution dose has been determined through the cumulative effect of the action of vibrations transmitted along several pathways. Based on

technical and medical data regarding the pathophysiological effects on the health of construction machinery mechanics, several categories of vibration risk have been established.

Based on the studies conducted and the tests on construction machinery during the technological work process, the following conclusions can be summarized:

a) the high levels of vibrations measured in the driver's work cabin generate diseases of the internal and auditory organs with states of discomfort, dizziness, anxiety, and temporary fatigue;

b) the most frequent psychosensory states that are generated by prolonged exposure to vibration levels above the permissible limit are characterized by fear, anxiety at work, decreased consciousness for short periods of time, osteoarticular and muscular pain;

c) vibration level, at accelerations measured above the permissible values, in construction machinery mainly affects the cardio-vascular system, lungs, internal organs, and osteoarticular system with short- or long-term consequences;

d) the safety solutions based on the results of the measurements consisted of the design and manufacture of devices for noise and vibration protection or the use of protection systems such as anti-vibration and vibro-insulating enclosures, mats, and cushions for the construction machinery work cabin.

When feasible solutions could not be found, measures were taken to modify the work schedule up to 2, 4, or 6 hours on the same construction machinery, so that the duration of exposure to vibrations was reduced, thereby reducing the harmful effects on the human body.

Thus, the work regimes on construction sites follow a work schedule depending on the severity of vibrations and the duration of human exposure in the control station and work cabin of the construction machinery.

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