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THE HARMFUL EFFECTS OF VIBRATIONS ON HUMAN

BY

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Abstract. This paper presents the harmful effect of vibrations on the human body. The vibration effect is quantified using the perception coefficient, K. In order to determine the perception coefficient, measurements were made in an area near the railways. Based on the measurements, the intensity of vibration and the degree of human vibration perception were determined. The results show that the vibrations generated by the railway transport and transmitted to the adjacent areas are highly perceptible, thus imposing vibration mitigation measures.

Keywords: coefficient of perception; intensity of vibration.

1. Introduction

Vibrations are dynamic phenomena commonly encountered in people's lives, with positive implications (heart beats, winding trees, vibrations produced by musical instruments), but also negative (tremors of buildings in earthquakes or those produced by means of transport).

Vibrations are analyzed for the purpose of highlighting and characterizing vibration sources, determining the vibration levels experienced both inside and outside buildings, their impact on human comfort, and highlighting control, protection and mitigation measures.

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The two harmful factors commonly occurring in traffic are noise and vibration. Vibrations have complex harmful effects on humans and the built environment, affecting the health of the human body, the quality of human work, the physical and mental comfort, the resistance of the building components, etc.

Both mechanical and acoustic vibrations can become dangerous for humans beyond certain limits. Studies on the harmful action of vibrations on the human body show that vibrations produce a number of harmful effects, both physiological and physical. For example, long-term exposure to low-frequency vibrations ranging from 5 to 15 Hz can lead to relative displacements of various organs, pulmonary hemorrhage, etc. (Ene, 2012).

Studies that investigate human comfort show that traffic vibrations generate discomfort, the annoyance increases with increased vibration, and these increase the disturbing effect of noise (Findeis, 2004; Gidlof-Gunnarsson, 2012). In addition, vibrations and noise are related to sleep disorders reported by people exposed to rail traffic (Howarth, 1991) and lead to changes in heart rate (Croy, 2013).

Vibrations can be transmitted to humans in three ways (Buzdugan, 1980):

a) on the whole body, through its entire surface, when it is under the effect of sound waves in the air, or immersed in water;

b) on the whole body, through the surface of contact with the environment, when the person is standing, sitting or lying down;

c) on parts of the body, for example hands that perform certain technological operations.

For the human body, the direction of the vibratory motion is also of interest (Buzdugan, 1982). Thus, if we would consider three rectangular axes to pass through the heart, the vibrations would be:

i) longitudinal, from head to toe;

ii) horizontal, perpendicular to the chest;

iii) horizontal, left-right.

It is customary to establish certain limits of vibration, depending on their physiological level. According to ISO 2631-1: 2001, we can talk about 3 criteria for assessing the harmful effect of vibrations on humans:

1. decrease in work efficiency (fatigue limit);
2. the health hazard (threshold of harm);
3. comfort limit (threshold of perception).

2. Quantitative Criteria for Assessing Vibrations

In order to set tolerable vibration limits, it is necessary to determine certain parameters to measure them.

The vibration strength level, as well as the noise level, is a subjective parameter, which depends on how human perceive the vibration. The same vibration is perceived differently by different people, depending on their sensory capacities. In practice, to measure the vibration strength level, the unit of measurement called pal is used. At the 1 Hz reference frequency, the vibration strength (in pal) is equal to their intensity level (in vibrar).

Most studies evaluate vibrations through the three kinematic sizes – acceleration, velocity and displacement – as well as frequency. Frequency has a particularly strong influence on the body's response, especially on high frequency vibrations, which are transmitted more easily through tissues, but it can not be considered as a determining factor in the physiological action of vibrations.

According to Zeller, the intensity of vibration is

$$Z = \frac{a_0^2}{f} = 16\pi^4 x_0^{\ 2} f^3 \text{, [cm}^2\text{/s}^3\text{],} \tag{1}$$

where: a_0 is the acceleration amplitude, x_0 – displacement amplitude for harmonic motion and f is the vibration frequency.

To define the degree of vibration perception by humans, the vibration level is quantifed as:

$$P = 10\log\frac{Z}{Z_1} \text{, [Pal].} \tag{2}$$

Considering $Z_1 = 0.5$ cm^2/s^3, one obtains

$$P = 10\log 2Z \text{, [Pal]} \tag{3}$$

In order to set the acceptable limits of vibrations, a series of parameters must be specified (Buzdugan, 1980):

a) the intensity of vibration;

b) frequency;

c) exposure duration;

d) direction of body vibration.

Fatigue threshold limits are given depending on the effective acceleration value. Dieckmann introduced a perception coefficient K taken as a measure of the effect of vibrations on man. The value of K is determined with the relation:

$$K = a_{ef}\,\frac{\alpha}{\sqrt{1+(f/f_0)^2}} \tag{4}$$

where: a_{ef} – weighting acceleration [m/s^2]; f – vibration frequency, [Hz]; f_0 = 10 Hz – frequency of reference; α = 18 s^2/m.

Table 1 gives the perceived steps and perceptual modes, depending on the *K* values, as they appear in the German VDI – Richtlinien 2057 standard.

Table 1
Vibration Perception Steps

Perception coefficient *K*	Step	Perception degree
0.1,..., 0.25	*A*	Imperceptible the threshold of perception Barely perceptible
	B	
0.25,...,0.63	*C*	Perceptible
0.63,...,1.6	*D*	Well perceptible
1.6,...,4	*E*	Strongly perceptible
4,...,10	*F*	Very strong perceptible
10,...,25	*G*	
25,...,63	*H*	
> 63	*I*	

Depending on the frequency, the effects of vibrations on the human body are different (Biriş, 2012):

a) vibrations below 10 Hz, specific to vehicles (automobiles 1.5,...,2 Hz, trucks 2,...,4 Hz, trains 3,...,8 Hz) at prolonged exposure can lead to general discomfort, chest pain, abdominal pain;

b) vibrations with frequencies between 10 and 40 Hz can cause headaches and problems with balance and walking.

For these reasons it is really justify the need to study vibrations in order to combat and reduce the harmful effects of vibrations on the human body.

3. Case Study

3.1. On-Site Measurements Description

In this paper it is presented a case study in witch the level of vibrations caused by trains and perceived in the adjacent area have been measured. Due to the development of the city without taking into account the problems that can arise due to the railroad, it has come to the unfortunate situation in which the city of Iasi is crossed by an important railway network, similar situations being encountered in most of the Romanian cities.

The studied area was chosen due to the presence near the railway of some important residential areas, but especially of a school, which influences the physical and psychological comfort of the children during the study. This negative influence is due to both the surface vibrations induced by the trains and the noise generated by them. Figure 1 shows the location of the railroad and adjacent areas.

Human comfort under the influence of vibrations that can be felt in residential buildings is also a problem. It is therefore imperative to reduce the transmission of vibrations to buildings to acceptable levels by designing an effective system to prevent them.

An important aspect is also the comfort at the pavement level, including within the schoolyard, starting from the idea that people's lives do not take place only inside buildings, but also outside.

Incorporating a system to prevent the transmission of vibrations from the source to neighboring areas will have the effect of improving comfort both at the urban and indoor areas.

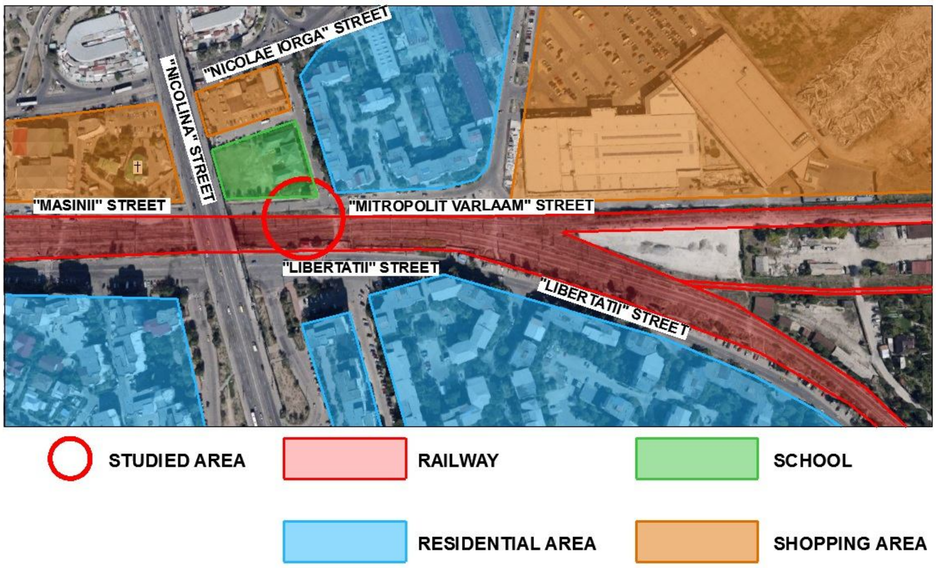

Fig. 1 – The studied area.

In order to study the effect of vibrations on the human body, a series of measurements of the acceleration amplitude were taken. The measurements were made in the Nicolina Bridge area, at the ground level, near the railway, on the sidewalk and near the school.

Measurements were made using 6 accelerometers mounted as follows: 3 horizontal accelerometers (Acc 0, Acc 2 and Acc 4) and 3 vertical (Acc 1, Acc 3 and Acc 5), one in the area near the railway, one at the sidewalk and one near the school (Fig. 2). The accelerometers (Fig. 3) transmitted the information to the ESAM Traveler acquisition system, which incorporates a dedicated ESAM CF software for data processing.

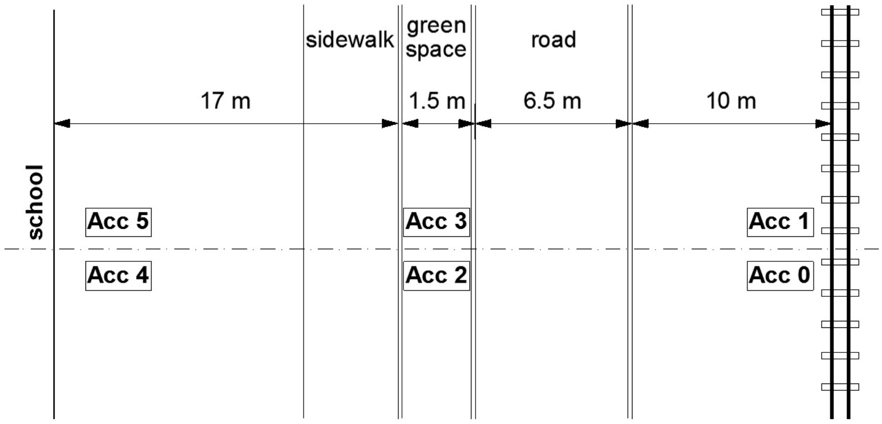

Fig. 2 – Location of accelerometers.

Fig. 3 – The setup of the accelerometers 4 (horizontal) and 5 (vertical).

Table 2 shows the types of trains that circulated during the measurements and for which the amplitudes of the vibrations produced were recorded. We note that all trains were trains for travelers, because during the recordings there were no freight trains, with a higher weight and which, implicitly, would have produced vibrations with higher amplitudes than those for passengers.

Table 2
Types of Passing Trains During the Tests

Nr.	Description
Test 1	Blank acquisition
Test 2	Train-blue arrow
Test 3	Tram
Test 4	Locomotive
Test 5	Locomotive + 1 wagon
Test 6	Locomotive + 2 wagons
Test 7	Locomotive + 3 wagons
Test 8	Locomotive + 4 wagons
Test 9	Locomotive + 2 wagons
Test 10	Locomotive + 6 wagons

3.2. Results of the On-Site Measurements

For the 10 tests the vibration amplitudes were recorded, their frequencies being between 0,...,40 Hz. This range of frequencies was divided into 3 intervals (0,...,15 Hz, 15,...,25 Hz, 25,...,40 Hz) for a consistent vibration amplitude reporting, and the maximum vibration amplitudes for each frequency range were centralized. For the obtained values the vibration intensity Z (according to relation 1), the degree of vibration perception, *P* (according to relation 3) and the perception coefficient, *K* (according to relation 4) were determinated.

Figs. 3,...,8 show the values of the perception coefficient for the 10 tests for each frequency range, differentiated in the horizontal and vertical direction of measurement.

From these measurements, tests 2, 7 and 8 stand out.

At the school level, in the horizontal direction, for test 2 (blue-arrow) there is a reduction in the perception coefficient between 50% and 89%, which has values above 2 (strongly perceptible) for the frequency ranges 0-15Hz and 25,...,40 Hz, and over 7 (very strong perceptible) for the 15,...,25 Hz range. For test 7, this reduction is between 38% and 85%, with values above 2 (strongly perceptible) for the frequency ranges 0,...,15 Hz and 15,...,25 Hz, and 0.9 (well perceptible) for the 25,...,40 Hz range. For test 8, the perception coefficient reduction, on the horizontal axis, is between 55% and 91%, with values above 3 (strongly perceptible) for the frequency range of 25,...,40 Hz, over 4 and 8 (very strong perceptible) for intervals 0,...,15 Hz and 15,...,25 Hz, respectively.

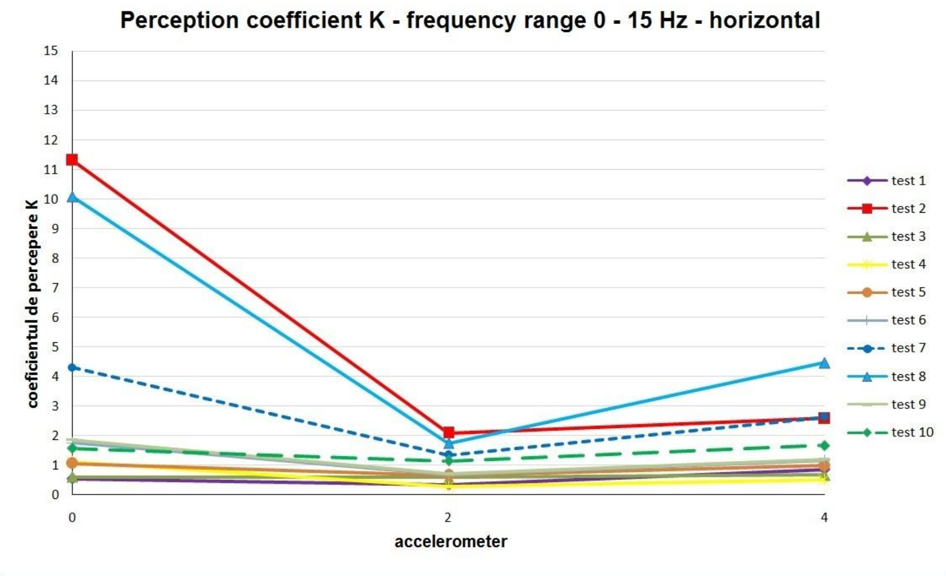

Fig. 3 – Variation of vibration perception, depending on the position of the accelerometer relative to the source – range 0,...,15 Hz, horizontal direction.

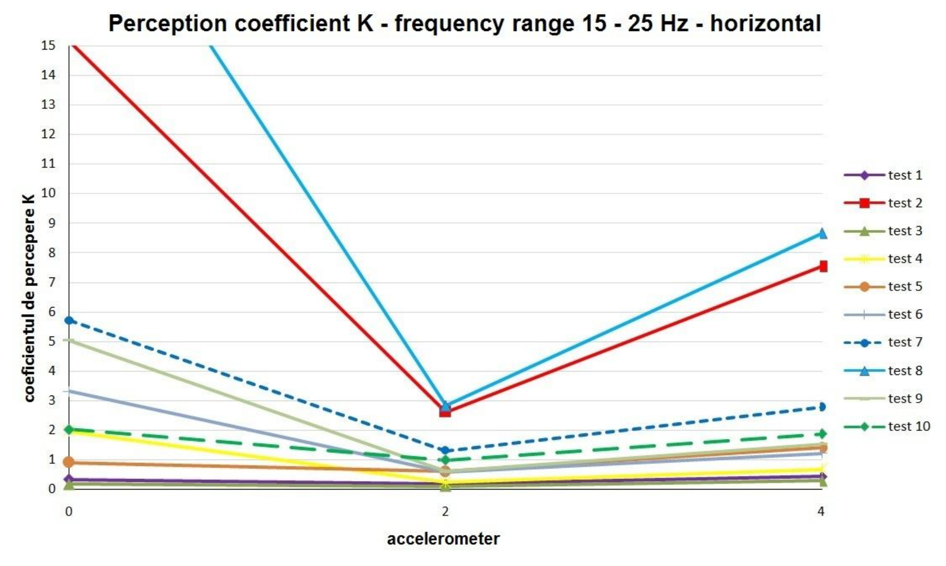

Fig. 4 – Variation of vibration perception, depending on the position of the accelerometer relative to the source - range 15,...,25 Hz, horizontal direction.

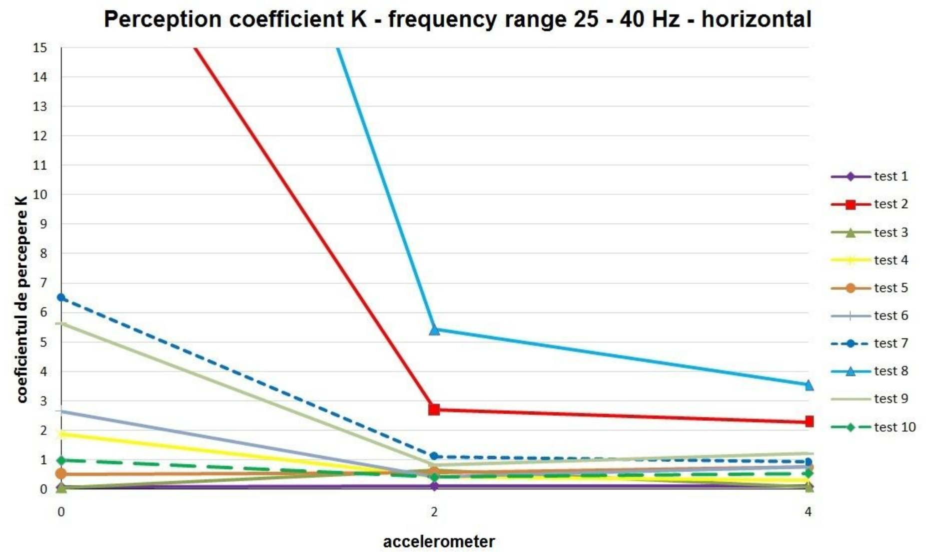

Fig. 5 – Variation of vibration perception, depending on the position of the accelerometer relative to the source - range 25,...,40 Hz, horizontal direction.

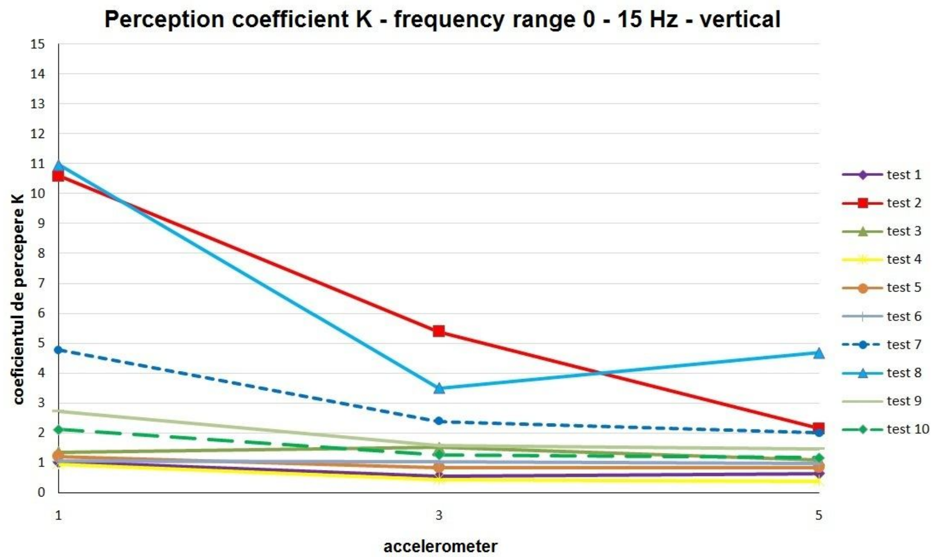

Fig. 6 – Variation of vibration perception, depending on the position of the accelerometer relative to the source - range 0,...,15Hz, vertical direction.

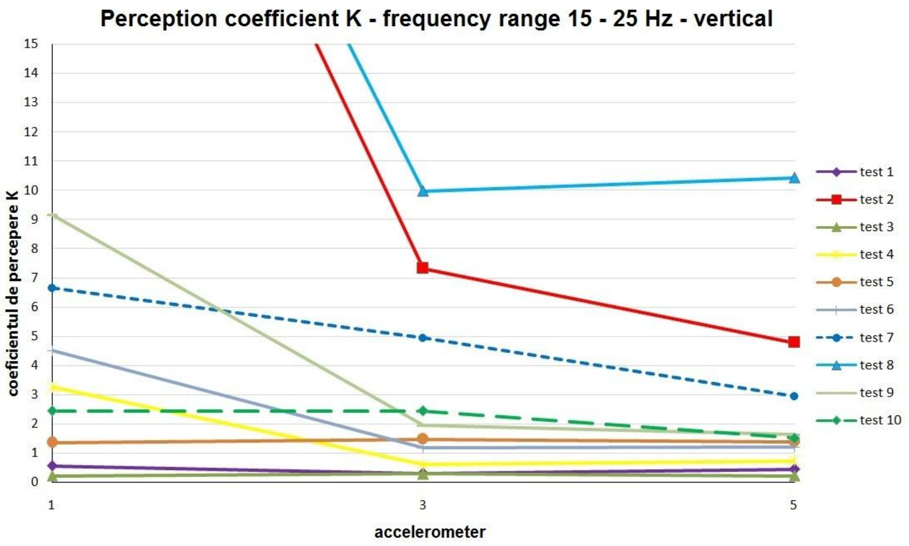

Fig. 7 – Variation of vibration perception, depending on the position of the accelerometer relative to the source - range 15,...,25 Hz, vertical direction.

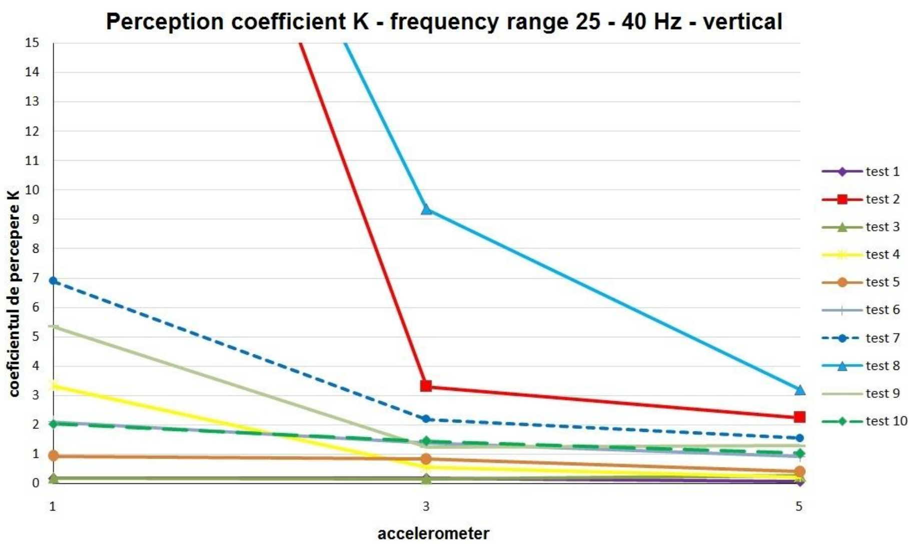

Fig. 8 – Variation of vibration perception, depending on the position of the accelerometer relative to the source - range 25,...,40 Hz, vertical direction.

At the school level, in the vertical direction, for test 2 (blue-arrow) there is a reduction in the perception coefficient between 79% to 94%, having values above 2 (strongly perceptible) for the frequency ranges 0,...,15 Hz and 25,...,40 Hz, and above 4 (very strong perceptible) for the 15,...,25 Hz range. For test 7, this reduction is between 55% and 77%, with values above 2 (strongly perceptible) for the 0,...,15 Hz and 15,...,25 Hz frequency ranges, and 1.5 (well perceptible) for the 25,...,40 Hz range. For test 8, the reduction in the perceiption coefficient is between 57% and 90%, having values above 3 (strongly perceptible) for the frequency range 25,...,40 Hz, over 4 (very strong perceptible) for the range of 0,...,15 Hz , and over 10 for the 15,...,25 Hz range.

3. Conclusions

Although there was no freight train within the time interval in which the measurements were taken, the frequency range for the vibrations produced by the passenger trains ranged between 10 and 40 Hz.

As can be noted from the graphs presented, the perception coefficients in the horizontal direction decrease at the sidewalk as a result of the amplitude damping due to the road infrastructure, only to increase in the area of the school.

Both in the horizontal and vertical directions, the value of perception coefficient near the school is the most reduced one, over all frequency ranges, yet having values that show that vibrations are strongly perceptible. For the 0-15 Hz frequency range, those vibrations that we are most sensitive to and which have a strong negative influence on comfort, the perception coefficient decreases on average by 65% in the vertical direction and by 56% in the horizontal direction. However, the K value is between 2 and 4, which means that vibrations are strongly perceptible.

Under these circumstances, and taking into account that there are also residential buildings in the railway area, a series of measures must be taken to isolate the traffic area through various procedures. These could be: the modernization of the components of the rail transport system, a vertical systematization of the area adjacent to the railways, which could help in the reduction of vibration transmission, the use of anti-vibration isolators.

The aim is to reduce the degree of the vibration perception in the adjacent urban area and to increase the degree of comfort.

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EFECTELE NOCIVE ALE VIBRAȚIILOR ASUPRA OMULUI

(Rezumat)

Articolul prezintă efectul nociv al vibrațiilor asupra organismului uman. Efectul vibrațiilor este cuantificat cu ajutorul coeficientului de percepere, *K*. Pentru determinarea coeficientului de percepere s-au efectuat măsurători într-o zonă din apropierea căilor ferate. Pe baza măsurătorilor s-a determinat intensitatea vibrației şi gradul de percepere a vibrației de către om. Rezultatele arată că vibrațiile produse de transportul feroviar şi transmise în zonele adiacente sunt puternic perceptibile, impunându-se astfel măsuri de amortizare a acestora.