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STUDY ABOUT THE INFLUENCE OF RAILWAYS UPON THE BUILDINGS IN THEIR NEIGHBORHOOD

BY

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Abstract. This paper aims to present the influence of the railway traffic upon the constructions placed in the neighbourhood of the railroads. The railway vehicles produce powerful and high intensity vibrations. Through the soil, the vibrations are transmitted to the foundations of nearby buildings. This can have consequences, such as settlements and cracks occurrence, even building collapse. The way such vibrations affect the buildings depends upon the distance at which constructions are placed, the traffic speed of the rolling material, the axle load, the state of the railway, the kind of soil and, last, but not least, the type of the foundation. The paper consists from a theoretical part dealing with characteristics of vibratory motion and where the vibrations of the rolling stock moving on joint track are shown, and a practical part where the results of the measurements are presented (regarding acceleration, speed, displacement, frequency) to highlight the detrimental effects of vibrations produced by the rolling stock in motion upon the buildings in the neighbourhood of the railways. Relevant photos are also given.

Key words: vibration; surface waves; cross waves; rolling stock; building.

1. Introduction

In order to maintain railway transportation, as a high level transportation means, it is necessary to have higher and higher speed and to

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continuously improve its comfort. Compared to the unevenness of road communications ways, on the railway, one cannot find such uneven platforms. However, due to unsuspended large weights and to wheels made of steel, very small unevenness can produce large shocks. The rolling stock running on a perfectly smooth railway is reduced and because of this reason the railway equipment exhibits problems with respect to shocks and vibrations. As the railway itself (that is very elastic) has a finite length and is provided with joints producing railway discontinuities that are transmitted to the surrounding ground, special protective measures should be installed in specific cases.

Other sources of shocks and vibrations can be:

a) the variation of the displacement speed;
b) rail joints movements;
c) displacements;
d) curves;
e) eccentricities and shape deviations of tires running surface;
f) pulls during shunting movements, brakes and accelerations.

However, the main source of vibrations sent to the ground lies in the impact of the rolling stock with the rail.

The vibrations can be produced both horizontally and vertically. The main origin of the horizontal vibrations lies in railway geometry and the wheel tire, while for the vertical vibrations, the main source is with uneven/irregular track surface and joint discontinuity.

The equipment suspension system has to provide shock decrease and vibration damping during displacement.

During travelling, the car gearbox can have six degrees of freedom, related to the three axes passing through its weight centre. Consequently, the following kinds of motions can appear:

a) vertical movements, generated by the irregularities of the track, which are taken over by the elastic component of the track;

b) rotation movements around the vertical axis, consequent to axle rocking, which are taken over by the suspension case;

c) cross movements (lateral oscillation), produced by the attack shocks when entering a bent and axle rocking, occurring because of tyre conicity; such motions are taken over by the suspension case or lateral case;

d) rotation movements around the transverse axis (pitching, galloping), generated by the action of the joints, when the vehicle wheel base does not correspond to the rail length; such motions are taken over by the elastic suspension components;

e) rotation movements around the longitudinal axis (lateral oscillation, rolling), due to track irregularities; such motions are taken over by the elastic suspension components;

f) longitudinal movements (recoil movement) produced by pulls during braking, starting or running; such motions are taken over by the oscillating suspension connections, buffer springs or traction device.

The horizontal and vertical motions of the suspension vehicle gearbox are produced by the periodic horizontal and vertical movement of the axles. As they have a periodic character and are continuously produced during operation, they are the basic vibrations of the vehicle gearbox, having a decisive impact upon running quality. Such vibrations present frequencies ranging between 8 and 20 Hz, much higher than basic frequencies.

The own frequencies of the vibrating systems of a vehicle depend upon the building features, dimensions, weight, and inertia moments. They are not influenced by the traffic speed. At a certain speed, the vibration frequency can be equal to the own vibration frequencies, leading to resonance.

In such a case, for the degree of freedom in question, very high amplitudes and accelerations occur.

The frequencies of disturbing vibrations caused by the rolling track cannot be acted upon. It is for this reason that intervention solutions are looked for, to affect the vehicle own vibration frequencies, within acceptable limits.

2. Vibrations of the Rail Vehicles that Are Moving on a Track with Joints

The mass-suspension-wheel system can be characterised with the following parameters (Fig. 1):

- the weight of the car case, M;
- the weight of the rolling wheel, m;
- the elastic spring rate, k;
- the rolling track elastic constant, k_1;
- the corrugated profile of the rolling track, $f = h(1 - \omega t)$;
- percussion (shock) S applied to the rolling wheel, occurring when passing over the joints of the rails;
- the coordinates of the weight centres, z_1, and respectively z_2, of the car case and of the wheel, respectively in the moment of static equilibrium;
- the system displacement speed, v.

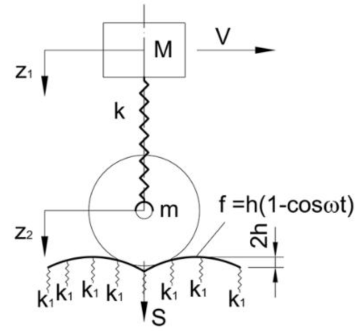


Fig. 1 – Diagram for the calculus of the mass-suspension-wheel system.

Below, the vibrations of a railway vehicle will be studied when moving on a rolling way with joints. The periodical wheel displacement over the joints produces repeated shocks.

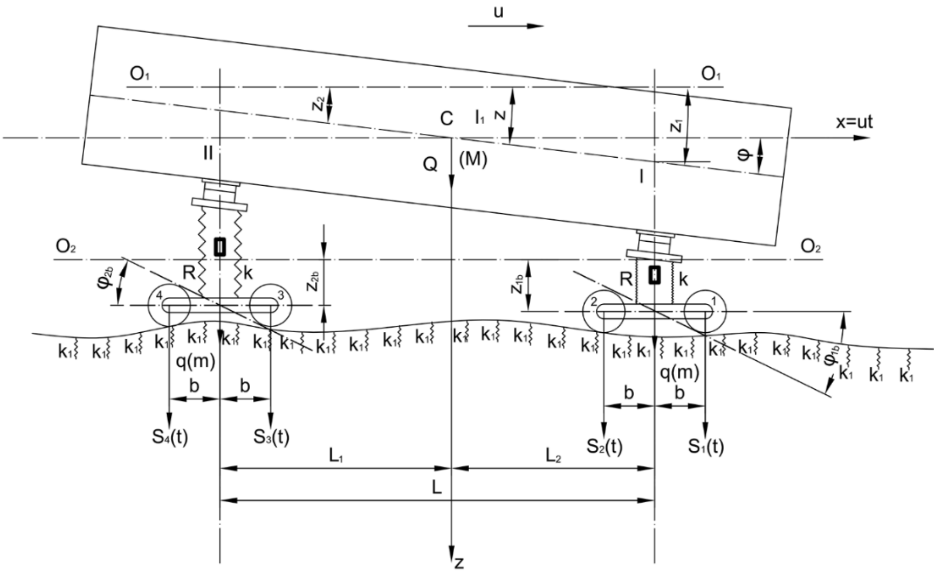


Fig. 2 – Diagram for the calculus of vibrations of a vehicle on rails during the movement on track with joints.

For the study of the vibrations, the diagram in Fig. 2 is taken, using the following notations: $O_1 - O_1$ is the axis passing through the vehicle weight centre in the moment of the static equilibrium; $O_2 - O_2$ is the axis passing through the vehicle unsuspended component in the moment of the static equilibrium; z, z_1, z_2 – are the coordinates of the weight centres of the suspended components and also of points I and II; z_{1b}, z_{2b} – are the coordinates of the weight centres of the unsuspended components; φ – is the rotation angle of the weight centres of the suspended component; φ_{1b} , φ_{2b} – are the rotation angles around the weight centres of the un suspended components (bogies); Q – is the weight of the suspended component; q – is the weight of the unsuspended component; M – is the mass of the suspended component; m – is the mass of the unsuspended component; I_1 – is the inertia moment of the suspended component of the vehicle related to the axis passing through the weight centre , also perpendicular to plane C_{xz}; I_b – is the inertia moment of the unsuspended component of the vehicle related to the axis passing through the weight centre , also perpendicular to plane C_{xz}; k – is the elastic constant of the vehicle suspension spring, k_1 – is the elastic constant of the railway suspension spring; v – the displacement speed of the vehicle.

The differential equations of movement have the form:

i) for the vehicle suspended part:

$$M\ddot{z} = -k\left(z + l_2\varphi - z_{1b}\right) - k\left(z - l_1\varphi - z_{2b}\right); \tag{1}$$

$$I_1\ddot{\varphi} = k\left(z + l_2\varphi - z_{1b}\right)l_2 - k\left(z - l_1\varphi - z_{2b}\right)l_1; \tag{2}$$

ii) for the first bogie:

$$m\ddot{z}_{1b} = -kz_{1b} - k_1z_{1b} + \frac{1}{2}\left[S_1(t) + S_2(t)\right]; \tag{3}$$

$$I_b\ddot{\varphi}_{1b} = -2k_1b^2\varphi_{1b} - \left[S_1(t) + S_2(t)\right]b; \tag{4}$$

iii) for the second bogie:

$$m\ddot{z}_{2b} = -kz_{2b} - k_1z_{2b} + \frac{1}{2}\left[S_3(t) + S_4(t)\right]; \tag{5}$$

$$I_b\ddot{\varphi}_{2b} = -2k_1b^2\varphi_{2b} - \left[S_1(t) + S_2(t)\right]b. \tag{6}$$

The bogie galloping processes expressed in equations (4) and (5) are not taken into consideration as they do not affect the vibratory processes of the vehicle box. Only equations (3) and (5) are considered here. After successive transformations and simplifications, it yields:

$$\ddot{z}_{1b} + \theta_3^2 z_{1b} = \frac{S}{2m}\left[\delta(t) + \delta(t-\tau_1)\right]; \tag{7}$$

$$\ddot{z}_{2b} + \theta_3^2 z_{2b} = \frac{S}{2m}\left[\delta(t-\tau_2) + \delta(t-\tau_3)\right]; \tag{8}$$

where: $\theta_3^2 z_{1b} = (k + k_1)/m$; τ_1, τ_2, and τ_3 – the interval from percussion start S_1, on the first pair of wheels, from the beginning of the action of percussions S_2, S_3 and S_4, on the second, third and fourth pair of wheels; $\delta(t)$ and $\delta(t - \tau)$ – represents Dirac function.

According to the diagram in Fig. 3, times τ_1, τ_2, and τ_3 are found with the help of the formulae in Table 1.

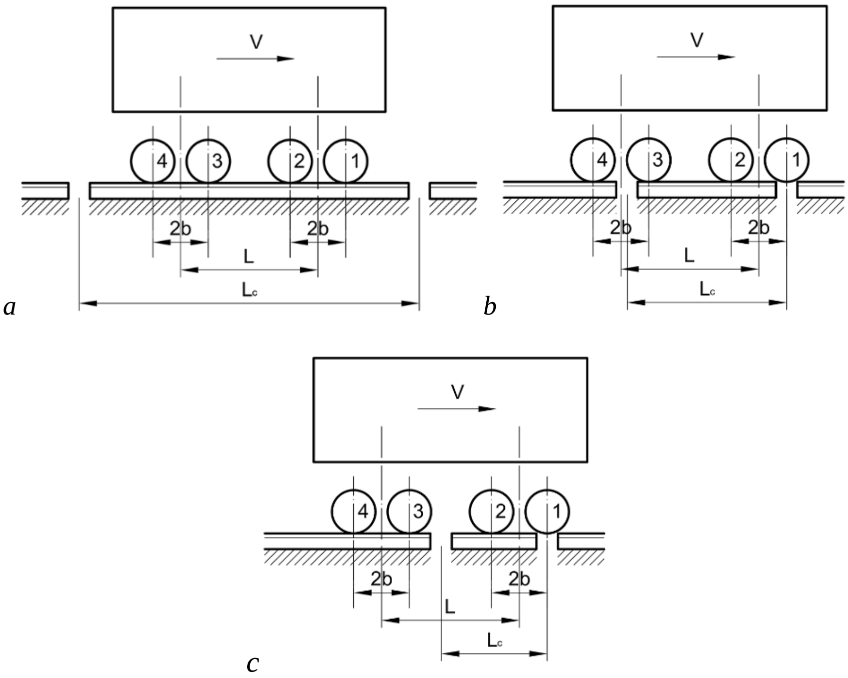


Fig. 3 – Diagram for the calculus of periods τ_1, τ_2, and τ_3.

Table 1

Values τ_1, τ_2, and τ_3

The ratio of length rail, L_c, and the wheelbase, L, *i.e.*, the distance $2b$	The values of periods		
	τ_1 for S_2	τ_2 for S_3	τ_3 for S_4
$L_c > L + 2b$ (Fig. 3 *a*)	$2b/v$	L/v	$(L + 2b)/v$
$L + 2b > L_c$ (Fig. 3 *b*)	$2b/v$	L/v	$(L + 2b - L_c)/v$
$2b < L_c < L$ (Fig. 3 *c*)	$2b/v$	$(L - L_c)/v$	$(L + 2b - L_c)/v$

The full calculus of the vibrations produced by the moving rolling stock is given in paper Darabonț *et al*. (1988, 461-482). All the results here depend on displacements.

3. Propagation of Vibrations in the Foundation Soil

The vibrations and shocks due to the rolling stock in motion more than often propagate along very large and away distances from the source. They do not propagate uniformly in all directions and in the same manner in all types of soil. Thus, in hard, compact soils, disturbances are transmitted at larges distances than in soft or granulary ground. The presence of underground water also affects the distance to which vibrations are transmitted. Such distances are very large and in several cases their intensity does not decrease. Vibrations propagate from the railway to the ground as compression waves, transverse waves and surface waves (Rayleigh waves).

Surface or Rayleigh waves exhibit the most outstanding importance as they are the main form of transmitting mechanical energy through the earth. In this way, about 67% of the source energy is transmitted through Rayleigh waves, 26% by shear waves and only 7% by compression ones.

In order to highlight how mechanical energy is transmitted thought the soil, the wave filed generated by a circular foundation at earth surface was taken. The ground is seen as a continuous, linearly deformable, homogeneous and isotrope halfspace (Fig. 4) (Richard, 1970; Woods, 1968).

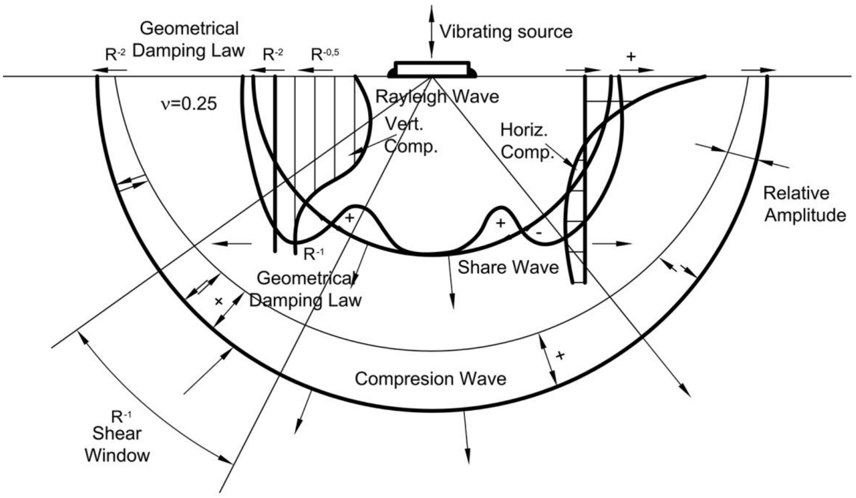


Fig. 4 – Wave displacement in an elastic halfspace.

The shear and compression waves propagate along a spherical wave front and the Raleigh waves move radially along a cylindrical wave front.

The earth volume met by the three types of waves increases progressively with distance *R* with respect to the source. Consequently, the radiating energy flux deceases with moving away from the source. The decrease expresses in the energy flux passing though the unit surface or displacement amplitude is called the Geometrical Damping Law. The motion of the particles to the compression waves is made in the direction of propagation, while the motion of the particles linked to the shear waves occurs perpendicularly to the wave front direction. The horizontal and vertical components of the particles associated to the Rayleigh waves vary with depth (see Fig. 4).

Besides the geometrical damping, vibrations energy dissipates as a result of matter damping. The amplitude of the Rayleigh waves decreases with distance, according to the relationship below:

$$A_2 = A_1\sqrt{\frac{R_1}{R_2}}\mathrm{e}^{-\alpha(R_2-R_1)}, \tag{9}$$

where A_1 and A_2 represent the amplitudes of the vibrations in two points situated at distances R_1, and respectively R_2 to the source. In this formula (the so-called Barkan Formula), the absorption coefficient α represents a percent of the damping value. The amplitudes of the wave body diminish much more rapidly, when the geometrical damping, is internally proportional to R^{-1}, and equal to R^{-2} along its surface.

The rolling stock in motion produces vibrations of high intensity magnitude. Because of them, the foundations of the buildings undergo high value settlements, cracks occur in the structure and gradually buildings damage and even lose their stability (Figs. 5 *a*, *b* and *c*).

Fig. 5 *a* – Settlements in column foundations.

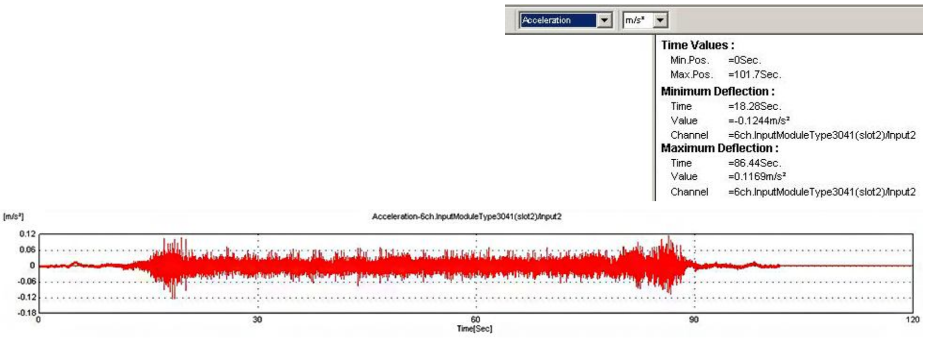
Fig. 5 *b* – Cracks occurring in the structure.

Fig. 5 *c* – Cracks occurring in the flight of stair ramp

In order to highlight such detrimental effects, measurements were performed in constructions situated in the neighbourhood of the railway, in Gherla, Cluj County, Romania. The most relevant values were recorded when a freight convoy made up of two locomotives and 20 carriages passes along about 60s. From these measurements, displacements, velocities and accelerations diagrams were drawn to use them as magnitudes to quantify the intensity of the vibrations. The results are given in the diagrams in Figs. 6 *a*, *b*, *c*, *d* and in the Tables 2 and 3.

Measurements were performed with the help of the PULSE Type 3560-C – Portable Data Acquisition Unit, up to 17 Input Channels and of the accelerometers Miniature DeltaTron Types 4507 and 4508.

The results of the measurements have been processed with the software *PULSE Labshop*. Measurements concerned constructions situated at a distance between 10 and 30 meters from the railway. The measuring device mentioned earlier measures the accelerations of the vibrations. The values found and the software *PULSE Labshop* were then used to find the values for speeds, displacements and frequencies. The effects of the vibrations upon dwelling buildings in the neighbourhood of the railway are also presented in relevant pictures shot on the ground.



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Acceleration  m/s²

Time Values :
  Min.Pos.      =0Sec.
  Max.Pos.      =101.7Sec.
Minimum Deflection :
  Time          =18.28Sec.
  Value         =-0.1244m/s²
  Channel       =6ch.InputModuleType3041(slot2)/Input2
Maximum Deflection :
  Time          =86.44Sec.
  Value         =0.1169m/s²
  Channel       =6ch.InputModuleType3041(slot2)/Input2
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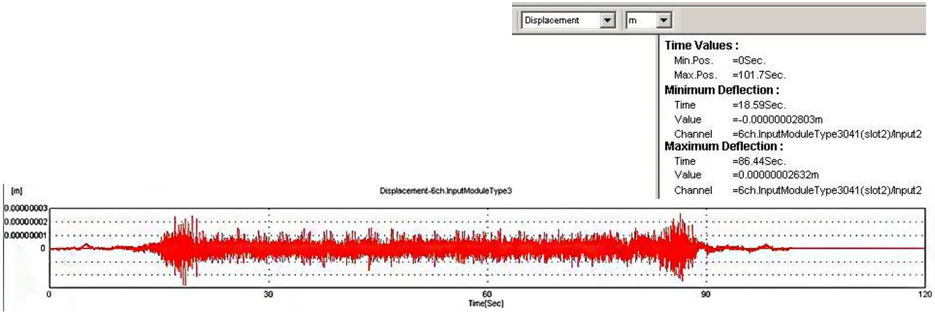
Fig. 6 *a* – Accelerations diagram.



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Displacement  m

Time Values :
  Min.Pos.      =0Sec.
  Max.Pos.      =101.7Sec.
Minimum Deflection :
  Time          =18.59Sec.
  Value         =-0.00000002803m
  Channel       =6ch.InputModuleType3041(slot2)/Input2
Maximum Deflection :
  Time          =86.44Sec.
  Value         =0.00000002632m
  Channel       =6ch.InputModuleType3041(slot2)/Input2
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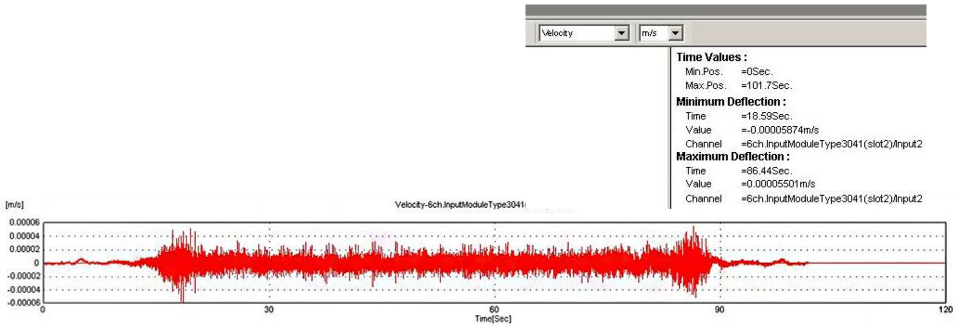
Fig. 6 *b* – Displacements diagram.



Time Values :
Min.Pos. =0Sec.
Max.Pos. =101.7Sec.

Minimum Deflection :
Time =18.59Sec.
Value =-0.00005874m/s
Channel =6ch.InputModuleType3041(slot2)/Input2

Maximum Deflection :
Time =86.44Sec.
Value =0.00005501m/s
Channel =6ch.InputModuleType3041(slot2)/Input2

Fig. 6 *c* – Velocities diagram.

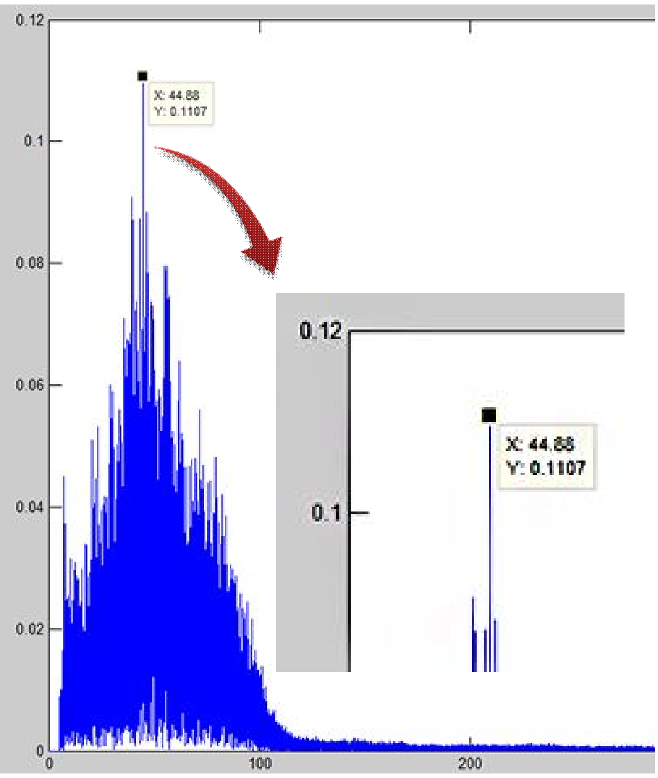


Fig. 6 d – Values for amplitudes and frequencies.

Table 2

Calculus of the Vibration Intensity Level, S [no. of vibrations] – for N

	a	**a^2**	**f**	**A**	**A_0**	**A/A_0**	**$\lg A/A_0$**	**S**
v1	0.1107	0.01225	44.88	0.00027	0.10	0.00273	–2.5638	–25.638

Table 3

Calculus of the Vibration Intensity Level, S [no. of vibrations] – for $N=10^6$

	$S_i - a$	$S_i/10$	$10^{\frac{S_i}{10}}$	N	1/N	$\sum n_i$	lg[...]	S
v1	0.1107	0.01107	1.025817255	10^6	1E-06	10^6	6.01107	60.1107

4. Conclusions

Following the measurements performed and the results, we found that the vibrations intensity level as calculated exceeds the admissible vibration intensity level.

In constructions placed in the neighbourhood of railways (about 20,...,30 m away) it is compulsory to provide antivibration protection means.

The protection measures should be provided to the buildings, the railway and rolling stock, in the design and erection stage or during service.

REFERENCES

Darabonţ A., Iorga I., Văiteanu D., Simaschevici H., *Şocuri şi vibraţii: aplicaţii în tehnică*. Edit. Tehnică, Bucureşti, 1988.

Esvelt C., *Modern Railway Track*. 2nd edition, Delft: University of Technology, MRT Productions, 2001.

Nerişanu R., *Studiul efectelor dăunătoare ale sistemelor de transport asupra construcţiilor*. Ph. D. Diss., Facultatea de Construcţii, Univ. Tehnică, Cluj-Napoca, 2014.

Pantea P., *Contribuţii la studiul şi elaborarea unor noi soluţii de protecţie prin ecranare antivibratorie a construcţiilor*. Ph. D. Diss., Facultatea de Construcţii, Univ. „Politehnica", Timişoara, 1997.

Richard F. E., Hall J. R., Woods R. D., *Vibrations of Soils and Foundations*. Prentice – Hall, Inc. Englevud Cliffs, New Jersey, 1970.

Woods R. D., *Screening of Surface Waves in Soils*. Proc, ASCE, nr. S.M.4, Juley, 1968.

STUDIU PRIVIND INFLENŢA CĂILOR FERATE ASUPRA CONSTRUCŢIILOR AFLATE ÎN VECINĂTATEA LOR

(Rezumat)

Este prezentată influenţa traficului feroviar asupra construcţiilor aflate în vecinătatea căilor ferate. Vehiculele feroviare în mişcare produc vibraţii de intensităţi foarte mari. Prin intermediul solului, aceste vibraţii sunt transmise fundaţiilor construcţiilor din apropiere, fapt ce are drept urmări, apariţia tasărilor, a fisurilor, putându-se ajunge chiar la colapsul construcţiei. Modul în care aceste vibraţii afectează clădirile depinde de: distanţa la care sunt amplasate construcţiile, viteza de circulaţie a materialului rulant, sarcina pe osie, starea tehnică a căii de rulare, tipul solului şi, nu în ultimul rând, tipul fundației. Lucrarea este alcătuită dintr-o parte teoretică, în care sunt prezentate caracteristicile mişcării vibratorii, vibrațiile vehiculelor care se deplasează pe o cale cu joante şi o parte practică, în care sunt prezentate rezultatele măsurătorilor (accelerații, viteze, deplasări, frecvențe) efectuate în vederea evidențierii efectelor negative ale vibrațiilor produse de materialul rulant în mişcare, asupra clădirilor amplasate în imediata apropiere a căilor ferate, precum şi fotografii relevante.