BULETINUL INSTITUTULUI POLITEHNIC DIN IAȘI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iași
Volumul 63 (67), Numărul 4, 2017
Secția
CONSTRUCȚII. ARHITECTURĂ

VIBRATION PROPAGATION IN ADJACENT AREAS OF RAILWAYS

BY

IRINA ŞTEFAN (OANCEA)*, MIHAI BUDESCU and MIHAELA MOVILĂ

“Gheorghe Asachi” Technical University of Iasi,
Faculty of Civil Engineering and Building Services

Received: November 17, 2017
Accepted for publication: December 25, 2017

Abstract. A phenomenon that has grown nowadays is transportation of people and goods. Increasing level of vibration near roads or railways is due to increased traffic. Studying vibration levels is required if roads or railways are built near residential areas. The values of these vibrations depend on several parameters: type of traffic (rail, metro or motorways), distance from source to structure, terrain stratification.

In this paper we study the level of propagation of traffic induced vibrations to structures located near them.

Keywords: vibration; railway traffic; wave propagation.

1. Introduction

Vibrations are primarily a mechanical agent with harmful effect on people, buildings, and only secondly a movement whose energy can be used in useful industrial processes. Vibrations can not be avoided, being a result of the operation of vehicles and machines, the action of the environment on structures (Ene & Pavel, 2012).

*Corresponding author: *e-mail:* irina.oancea@tuiasi.ro

Vibratory movement at a point in a flexible system may be the response to an excitation applied to the system, the characteristics of the system depending on its dynamic properties. Excitement may be dynamic, expressed by forces, couples or pressures, or kinematic, expressed by the displacement, velocity or acceleration of a point in the system. Likewise, the response can describe the movement of a point in the system or the force transmitted at that point.

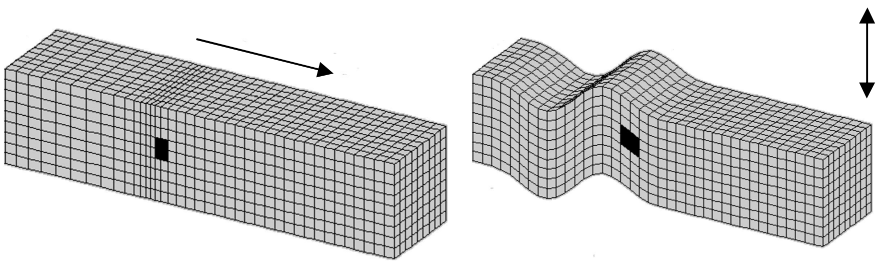
Mechanical vibrations transmitted to buildings from different sources of vibration can cause various damage: wall cracks, cracks in the plaster and their falling, foundation settlement, etc., or even the collapse of the entire building. The effects of vibrations on buildings can be easily assessed by measuring various vibration parameters (amplitude, velocity, or acceleration) needed to determine vibration intensity with the help of existing devices.

Vibrations transmitted to the environment, depending on their source and intensity, negatively affect not only buildings but also their users, reducing the comfort of people, whether we are talking about comfort inside buildings or urban comfort.

2. Theoretical Notions About the Transmission of Vibrations

2.1. Wave Propagation

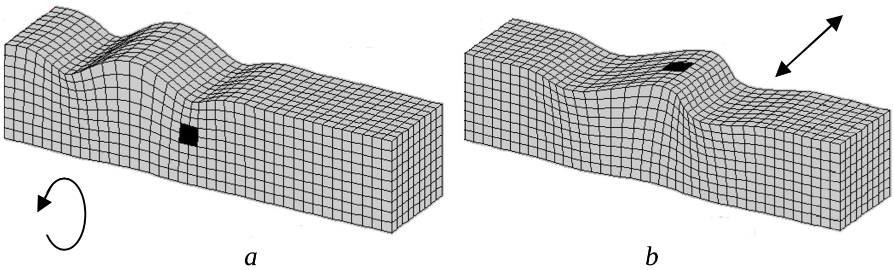
Traffic induced vibrations can be propagated in the field, by volume waves and surface waves (Henwood & Haramy, 2002). Volume waves are primary waves (or compression waves, denoted by *P*) and secondary waves (shear waves, denoted by S). They propagate across the earth's mass (Fig. 1). The propagation velocity of the primary waves is 7,...,8 km/s and the secondary waves' velocity is 4,...,5 km/s.



a *b*

Fig.1 – Primary waves *P* (*a*) and secondary waves *S* (*b*).

Surface waves (Rayleigh waves, denoted *R* and Löve waves, denoted by *L*, propagate along the terrain surface (Fig. 2). Rayleigh waves are elliptical longitudinal waves, perpendicular to the surface and produce volume and shape deformations, Fig. 2 *a*, and the propagation speeds of these waves are 5,...,7 km/s. The Löve waves are transverse waves, located in the tangent plane, where the particle movement is perpendicular to the wave propagation direction, Fig. 2 *b*. The propagation velocities of these waves are smaller and have values of 0.5,...,5 km/s.



a *b*

Fig.2 Surface waves Rayleigh (*a*) and Löve (*b*).

Vibrations due to traffic propagate in the nearby environment via surface waves (Fig. 2). The amplitude of these waves decreases with increasing distance from the vibration source, this attenuation being related to the type of soil, its humidity and temperature.

2.2. Traffic Vibrations and Their Effects on the Environment

Taking into account traffic induced vibrations has become an increasingly important issue in designing and sizing traffic systems.

In the past, residential buildings were more dispersed, but nowadays the cities have expanded, with the traffic system developing both underground and aboveground. In major cities, residential areas have emerged right near traffic areas.

Vehicles produce vibration, affecting not only the comfort and health of the passengers, but also the structures located near traffic areas (Fig. 3). Table 1 presents the factors that influence the intensity of traffic vibrations and their perception inside buildings.

Table 1

Vibration Intensity and Perception Depends on:

Source	Transmission	Receiver
- Type of traffic; - Vehicle parameters; - Drive speed.	- Distance between source and receiver; - Soil absorption; - Land configuration.	- Structure parameters; - The location of the structure.

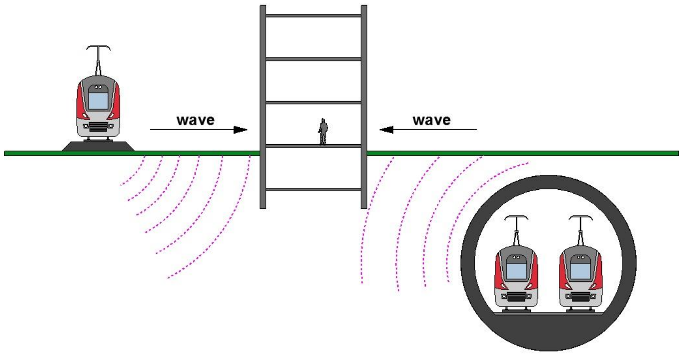


Fig. 3 – Generating vibrations from aboveground and underground railway traffic.

In order to quantify the vibrations level, it is necessary to establish a level of their "strength". The amplitude of vibrations in accelerations, velocities or displacements (in maximum values) are not always sufficient to characterize this level. Moreover, if we refer to the human being, the perception of vibration and noise varies greatly from individual to individual, as it is dependent on sensory perceptual capacity and may be related to the size and weight of internal organs (each organ having its own characteristics) (Fig. 4).

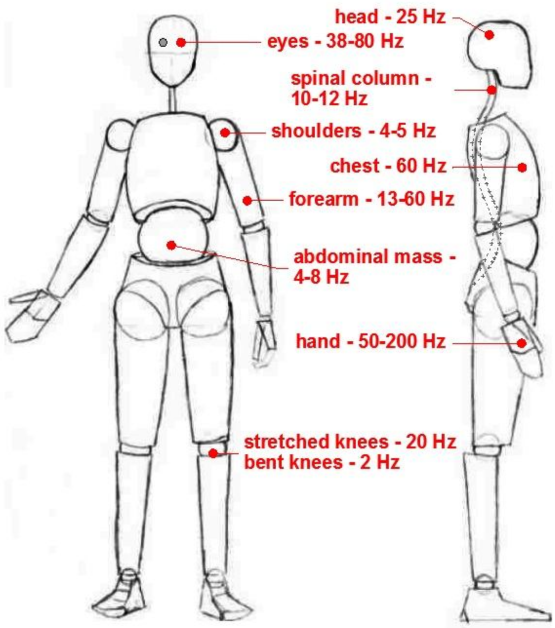


Fig. 4 – Dynamic characteristics of the human body (adaptation after Rasmussen, 1982)

The perception of vibrations by the human body depends on the position of the body (lying down, standing or walking), the excited organ (as a resonance depending on the frequency of the action), the type of vibrations (harmonic or composite), the amplitude of the vibrations, etc., see Table 2 (Ene & Pavel, 2012).

Table 2
Effects of Vibration on the Human Body, for the Frequency of 1 Hz.

Vibration strength, [pal]	Effects on the human body
0,…,10	Vibration at the threshold of perception, depending on the position of the body.
10,…,20	Vibrations clearly perceived, acceptable for living rooms.
20,…,30	Vibration due to traffic, admissible for people in buildings.
30,…,40	The vibrations that a man in a quiet-moving vehicle can bear. Unpleasant vibrations.
40,…,50	Disturbing vibrations, produced by vehicle and elevator movement
50,…,60	Strong vibrations felt by humans in vehicles, bearable without harm to health (only if they act for a very short time)
60,…,80	Vibrations that cause physical injuries, sickness, touch-ache (especially at high frequencies)

Obviously, the action of vibrations is also imprinted on buildings, depending on the intensity of vibration. The effect of vibrations on structures depends primarily on the chosen foundation system, which, if massive, can absorb vibrations and their transmission in structure is much diminished.

Traffic generates vibrations for adjacent structures, which can be amplified if their predominant frequency is close to the actual soil frequency. If the two frequencies coincide, the resonance phenomenon occurs, which will lead to vibration amplification. The resonance phenomenon occurs mainly at high structures which are localized near the vibration source (Tomlinson & Woodward, 2014).

2.3. Study of Vibrations Near Railways

Vibrations due to rail traffic may have negative effects on communities located near railways. There are more and more frequently the situations in which vibrations can cause structural damage to buildings, but the most important thing is the effect on people inside them (Kouroussis *et al.*, 2014).

Propagation of waves depends on a number of factors, such as the quality of the tread infrastructure, the weight of the means of transport, the number of wagons, its travel speed and the terrain stratification (Monteiro, 2009).

Table 3 shows the influence of factors on the level of vibrations transmitted to the structures.

Table 3
Influence of factors on vibration level

Factor	Influence
Suspension of the vehicle	If the suspension is rigid vertically, then the transmitted forces will be higher. On freight trains, only the primary suspension affects the vibration levels, the secondary suspension has no effect.
The quality of the wheels	The ruggedness and flatness of metal wheels is the main cause of vibration production.
The railway rolling path	Rigidity of the tread or defects of it may produce vibrations.
Track support system	On railway systems, rail support is one of the major components in determining ground vibration levels. The highest vibrations are produced by the rail which is rigidly fixed to a concrete crosspiece. Vibration levels are much lower when using special vibration control systems such as elastic fasteners or ballast pads.
Speed	The high speed of movement will automatically produce higher vibrations.
The depth of the vibration source	Vibrations produced by the subway will have completely different features than those produced by above ground rail transport.
The type of soil	In general, the vibration level is higher for clay soils than for sandy ones.
Soil stratification	The soil layers will have a substantial but unpredictable effect on the vibration level, since each layer has different characteristics.
Groundwater	The presence of water can influence the level of vibration transmitted.
Depth of frost	Propagation of vibrations is lower when the ground is frozen.

The magnitude of waves generated by rail traffic increases gradually and decreases according to the number of wagons, and the propagation velocity is correlated with the distance between the runway and the point where it is received.

3. Case Study

3.1. Study Description

The case study in this paper was carried out in Iaşi, in the Nicolina Bridge area, at ground level near the railway and the school in the area.

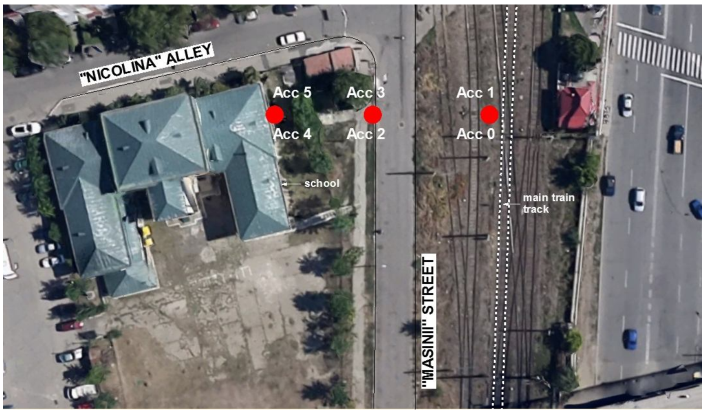


Fig. 5 – Location of accelerometers.

The measurements were made with 6 accelerometers mounted as follows: 3 horizontal accelerometers disposed perpendicular to the railway (Acc 0, Acc 2 and Acc 4) and 3 vertical (Acc 1, Acc 3 and Acc 5), one in the area near the rail, one at the sidewalk and one near the school (Figs. 5 and 6). The location of the accelerometers and the types of trains for which the recordings have been made are described in the article "The Harmful Effects of Human Vibrations" by the same authors. (Ştefan *et al*., 2017).

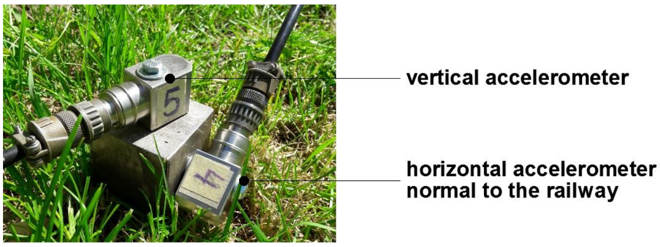


Fig. 6 – Accelerometer setup.

Using the ESAM CF software, the data transmitted by the accelerometers to the ESAM Traveler acquisition system, have been processed.

The vibrations produced by the action of the trains are a random, non-stationary, evolutionary signal, varying over time. To analyze these signals, the ESAM Traveler software uses the Fast Fourier Transformation (FFT). The most important property of FFT is the filtering (the signal is obtained by filtering with a pulse-response filter). Other important properties of the Fourier transformation are modulation (shift in spectrum) and conservation of signal energy.

3.2. Results of the On-Site Measurements

Of the 10 tests performed to exemplify the wave propagation through the soil, test 8 was chosen, as it showed the highest level of recorded vibration amplitude.

Figs. 7,...,18 show the near-school records for each accelerometer, showing the acceleration over time and the dependence between acceleration and frequency using the FFT.

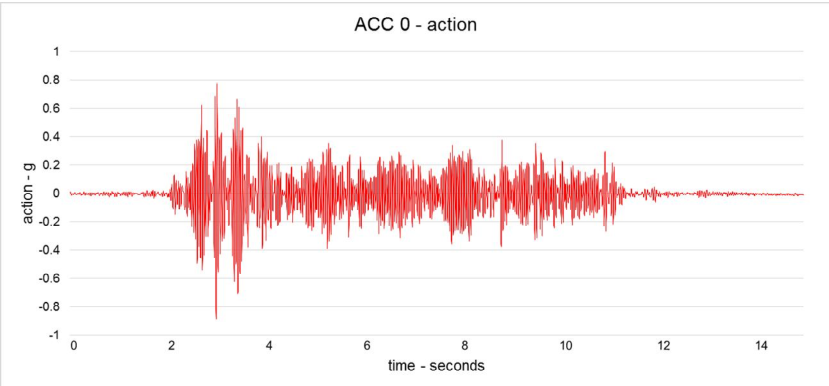


Fig. 7 – Acceleration-time recording - accelerometer 0 (horizontal position).

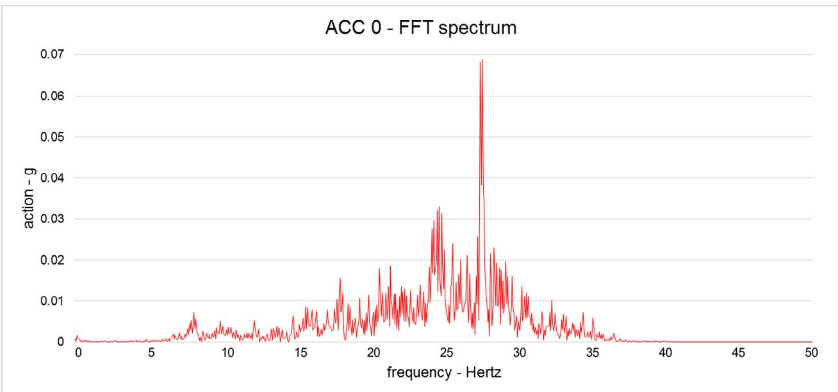


Fig. 8 – FFT – acceleration-frequency - accelerometer 0 (horizontal position) - Fig.7.

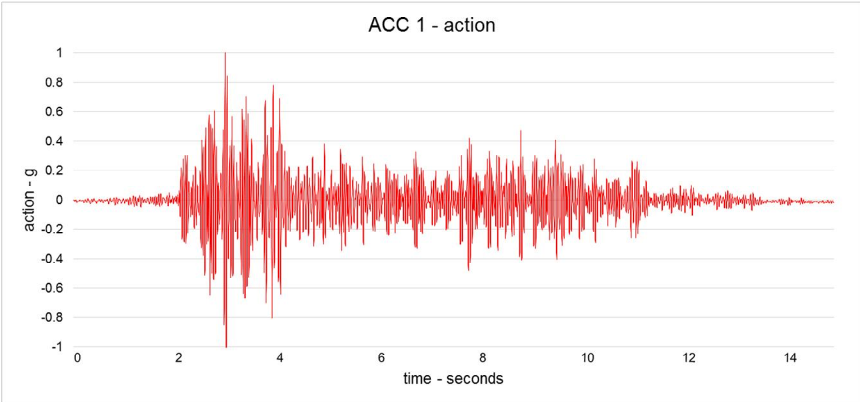


Fig. 9 – Acceleration-time recording - accelerometer 1 (vertical position).

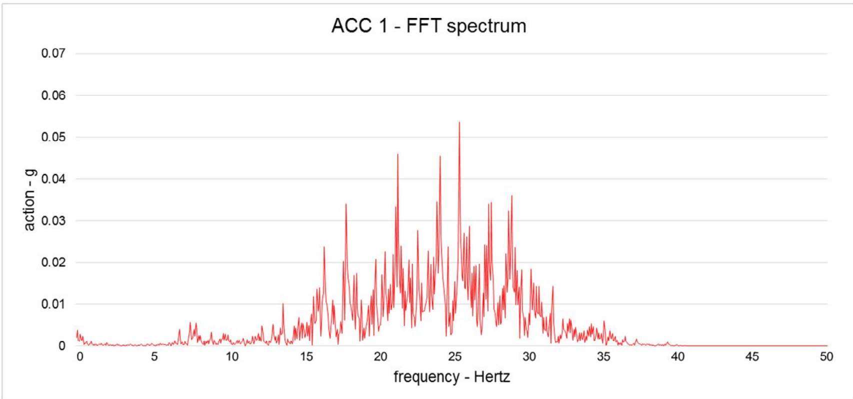


Fig. 10 – FFT – acceleration-frequency - accelerometer 1 (vertical position) - Fig. 9.

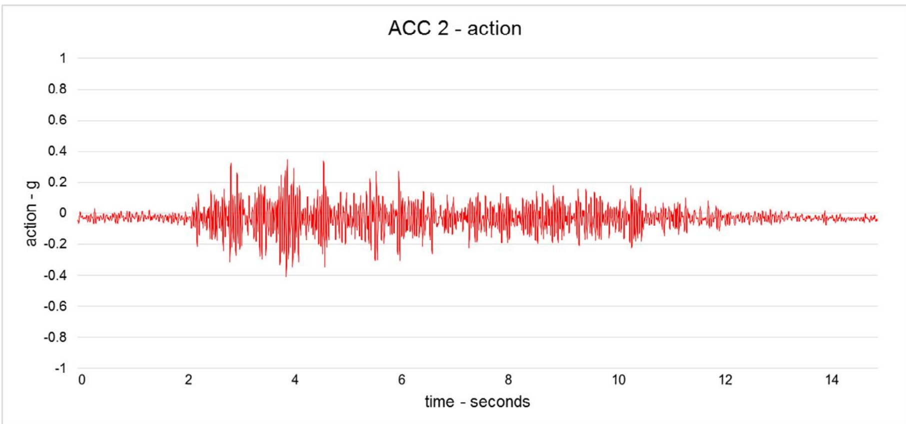


Fig. 11 – Acceleration-time recording - accelerometer 2 (horizontal position).

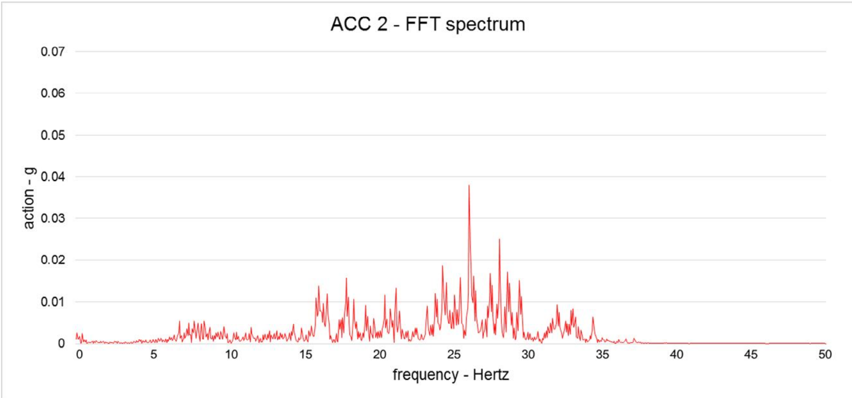


Fig. 12 – FFT – acceleration-frequency - accelerometer 2 (horizontal position) - Fig. 11.

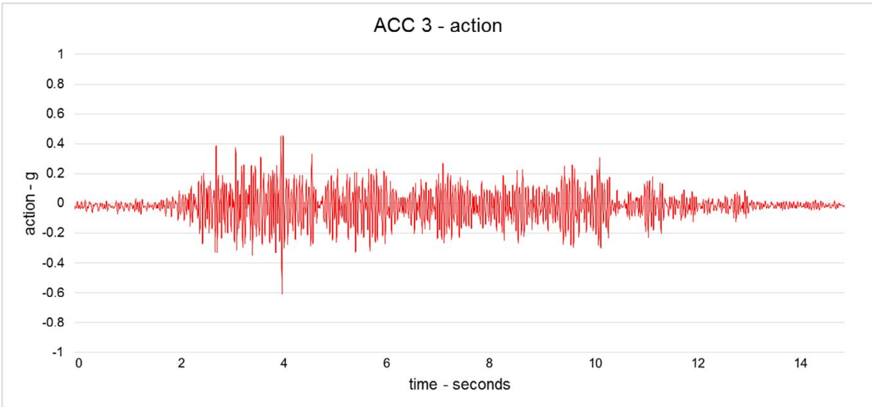


Fig. 13 – Acceleration-time recording - accelerometer 3 (vertical position).

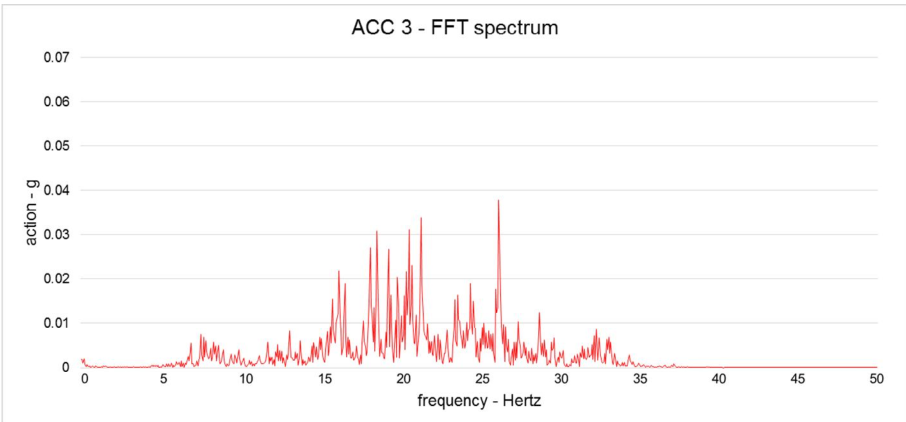


Fig. 14 – FFT – acceleration-frequency - accelerometer 3 (vertical position) - Fig. 13.

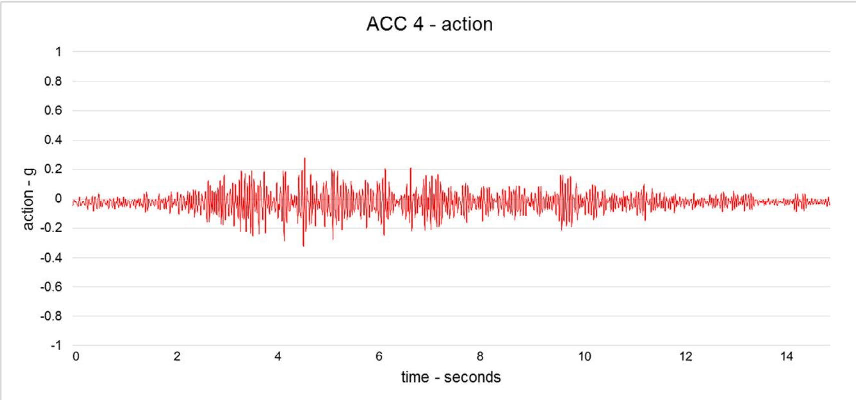


Fig. 15 – Acceleration-time recording - accelerometer 4 (horizontal position).

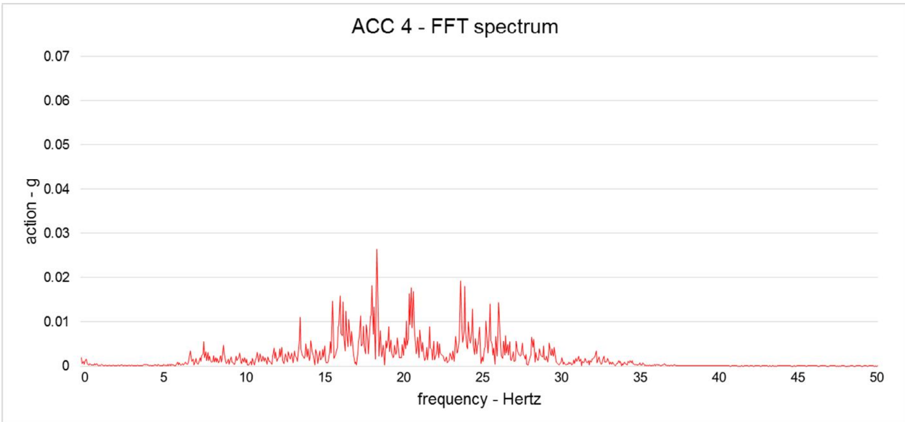


Fig. 16 – FFT – acceleration-frequency - accelerometer 4 (horizontal position) - Fig.15.

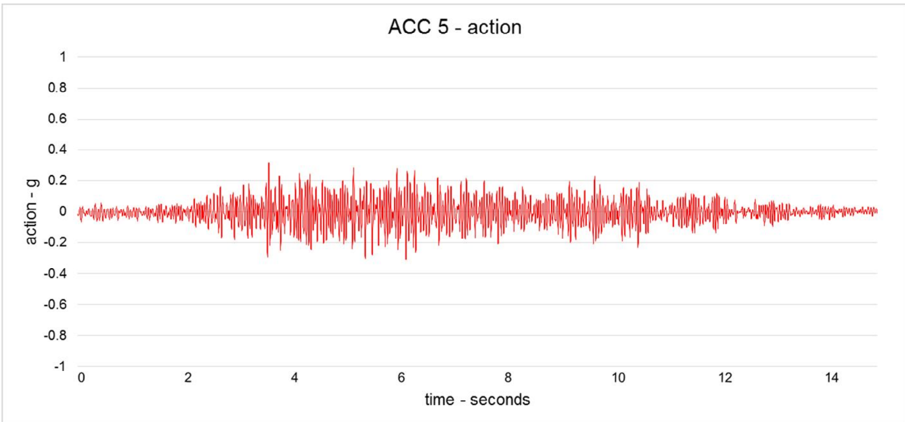


Fig. 17 – Acceleration-time recording - accelerometer 5 (vertical position).

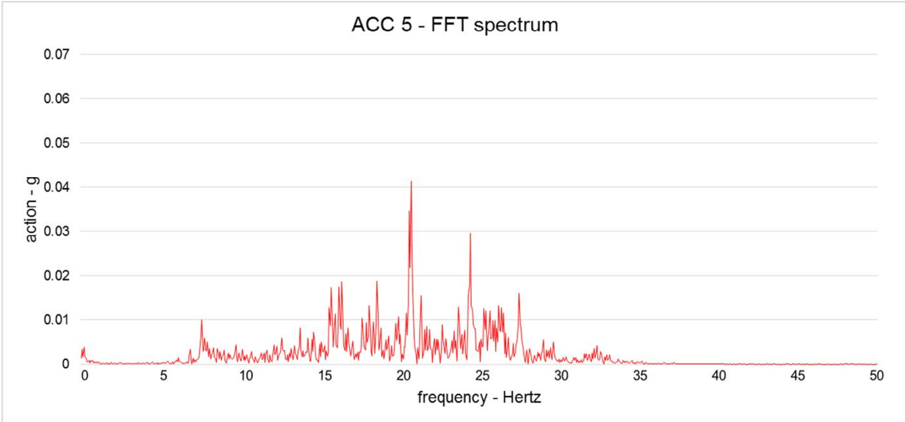


Fig. 18 – FFT – acceleration-frequency - accelerometer 5 (vertical position) - Fig. 17.

It can be noted that during the recording period no freight train was intercepted, which would certainly have led to much higher levels of acceleration amplitudes.

In order to track the propagation of the waves, for this test, there were made comparisons between the recordings made at the railway level, at the pavement level and those recorded near the school, being presented as an FFT analysis, referring to the horizontal direction (Fig. 19), as well as the vertical one (Fig. 20).

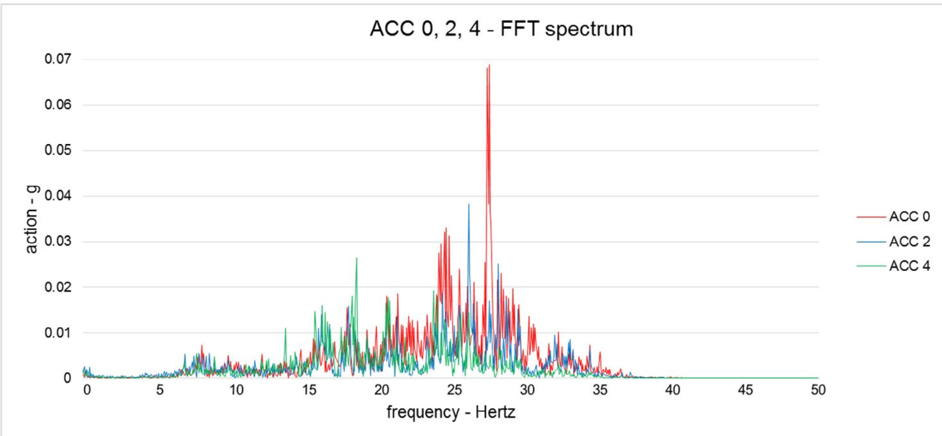


Fig. 19 – FFT horizontal direction - accelerometers 0,2,4.

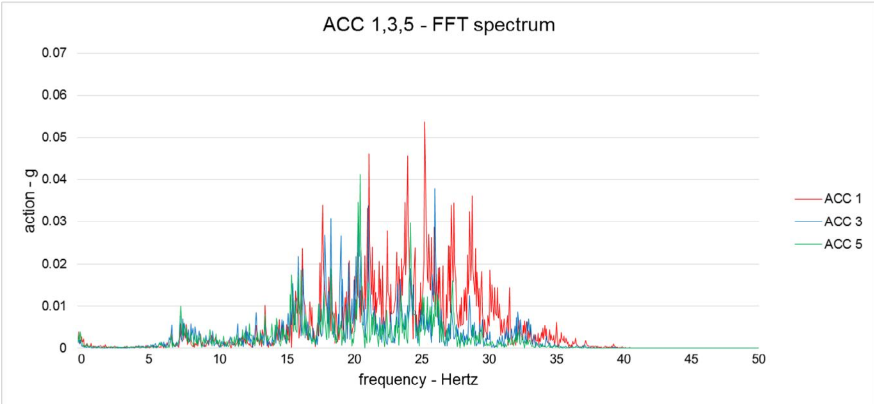


Fig. 20 – FFT vertical direction - accelerometers 1,3,5.

As one can see, the vibration level drops significantly from the railroad to the school. A first cause would be the distance between the railway and the school (35 meters). Another cause would be stratification of the soil in the area. The highest amplitude values were obtained in the frequency range 20,...,30 Hz, the maximum values being recorded in the vicinity of the 25 Hz frequency, which may particularly affect the concentration capability (head - see Fig. 4). Test 8, unlike other tests, records high values over a higher frequency range, namely 15,...,35Hz.

4. Conclusions

The problem of traffic-based vibration has become quite important due to the urbanization of the areas near the railways. For this reason it is necessary to determine the level of these vibrations and their influence on the buildings and the population inside, as well as to find methods for their mitigation.

The study shows a high level of vibration, in acceleration terms, at school level. The attenuation due to distance reduces the amplitudes of the spectral components by about 50%, given that during the test, about 6 hours, no freight train passed.

It is important to note that these vibrations have a range of 15,...,35 Hz component frequencies that can affect long-term exposure to all internal organs of children, school users in the immediate vicinity of the railways.

The same situation can be found for all collective dwellings along this railroad.

One of the solutions for solving the problems generated by this railroad that transits the city is to place vibration mitigation barriers along the railways and noise protection screens, as noise is induced simultaneously with vibrations.

Obviously, all this can be solved by eliminating the harmful effects of the source, which means very large investments; hard to assume that they can be solved in a close time horizon. These measures require the restoration of the embankment and the change of all suspension systems of the means of transport that pass through the area.

REFERENCES

Ene G., Pavel C., *Introducere în tehnica izolării vibraţiilor şi zgomotului*, Edit. Matrixrom, Bucureşti, 2012.

Henwood J.T., Haramy K.Y., *Vibrations Induced by Construction Traffic: a Historic Case Study*, Federal Highway Administration, Denver, CO 80225, 2002, link: http://www.dot.ca.gov/hq/esc/geotech/geo_support/geophysics_geology/pdf/geophysics_2002/043henwood_construction_vibrations.pdf.

Kouroussis G., Florentin J., Conti C., Verlinden O., *Building Vibrations Induced by Railways: an Analysis of Commonly used Evaluation Standards*, The 21st International Cong. on Sound a. Vibration, Beijing, China, July 13-17, 2014.

Monteiro M., *Vibrations Induced by Trains. Case Study: Extension of Track Platform of Gare do Oriente*, 2009, link: https://fenix.tecnico.ulisboa.pt/downloadFile/395139464839/Abstract_ManuelMonteiro.pdf.

Rasmussen G., *Human Body Exposure and it's Measurement*, J. of the Acoustical Society of America, **73**, 2229 (1983).

Ştefan (Oancea) I., Budescu M., Movilă M., *The Harmful Effects of Vibrations on Human*, Bul. Inst. Politehnic, Iaşi, **63 (67)**, *3*, 33-44 (2017).

Tomlinson M., Woodward J., *Pile Design and Construction Practice* (Sixth Edition), CRC Press, 2014.

PROPAGAREA VIBRAȚIILOR ÎN ZONELE ADIACENTE CĂILOR FERATE

(Rezumat)

Un fenomen ce a luat amploare în zilele noastre este transportul populației şi al mărfurilor. Creşterea nivelului de vibrație în apropierea drumurilor sau a căilor ferate se datorează creşterii traficului. Studierea nivelului vibrațiilor este necesară dacă drumurile sau căile ferate sunt construite în apropierea zonelor rezidențiale. Valorile acestor vibrații depind de mai mulți parametri: tipul de trafic (feroviar, metrou sau autostrăzi), distanța de la sursă la structuri, stratificația terenului.

În această lucrare se studiază nivelul propagării vibrațiilor din trafic la structurile situate în apropierea acestora.