The Influence of Traffic Vibrations on Buildings and Human Inside the Buildings

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Abstract

The article talks about the very intricate connection between traffic vibrations and their impact on the masonry buildings and their residents. The paper highlights that the vibrations that come from traffic can affect the building and cause serious structural problems like cracks and deformations that compromise the safety of the building and can be harmful to its occupiers. These series of vibrations also act as a major cause of discomfort and health issues for the occupants of the vehicles, including painful headaches, stress, and sleeping disturbances. To limit these effects, the article draws attention to the development of effective strategies such as the addition of dampers or insulators to the building foundation or the strengthening of the structural elements. However, there still exists a gap in the research in this area, and more studies should be conducted to provide more knowledge of the problem and the viable solutions. In general, the article underlines the necessity of solving this problem to save the buildings and their residents from the bad outcomes of vibrations.

Keywords: *traffic-induced vibrations, human perception of vibration, comfort, Vibrations, safety of buildings*

1. Introduction

Vibrations propagating from the ground into buildings can significantly affect not only the structural integrity of these buildings but also the well-being and comfort of their occupants. These problems go beyond major physical damage or accelerated deterioration of building materials. They interfere with people's daily lives, making their lives difficult regarding rest, and in extreme cases might be a health threat. Users of the buildings can be negatively influenced by forms ranging from minor nuisances to dangerous health consequences.

One of the main problems with ground vibrations is their influence on the structural health of buildings. Incessant vibrations impact a building in a manner that microcracks are formed in the foundation and walls, which in turn leads to a decrease in the building's stability and safety. Besides, the vibrations can accelerate the wear and tear of building materials, causing the building to age prematurely, which requires more frequent repairs and maintenance, thus increasing the owner's and manager's financial burdens. This dilemma becomes more severe when there are other hazards, such as additional wind-induced vibrations [1].

Apart from the structural effects, the human consequences of these vibrations cannot be overestimated. Inside buildings, vibrations can disturb the peace and calm that residents hope from their living and working circumference. The vibrations' physical feel can be especially annoying, confusing focus and relaxation. Most often, the constant presence of low-frequency vibrations, in the range of 5 to 25 Hz, corresponding to the resonant frequencies of human internal members can lead to more serious health problems. It can cause sleep trouble, which in turn can lead to a range of psychological and physical health problems such as headaches, chronic fatigue, and even neurotic cases. Research conducted in many areas [2,3,4,5] strengthens this and stresses the importance of further examination and action on the subject.

In [2], the evidence of vibration effects on human sleep quality is presented, while [3] takes up a more medical approach to the impacts of vibration on heart rate. [4] highlights the special effects of low-frequency vibration on human health, while [5] provides a global overview of the effects of transport vibration as an injurious factor for physical and mental health.

Despite the large research on this subject and the presence of normative standards to relieve the effects of vibration, there remains a gap in our full understanding and management of this problem. The subjective nature of vibration perception– how vibrations are perceived differently by people – poses a great challenge to the development of universal guidelines and solutions. These perceptual differences are impacted by several factors, including a person’s health status, their sensitivity to motion, and even a psychological predisposition to stress or concern due to environmental conditions. Increasing understanding of the impacts of ground vibration on people and buildings has led to changes and updates to both national and international regulatory standards, such as those embodied in the ISO standards [6,7].

These modifications reverse ongoing research and an increasing consciousness of the necessity for a comprehensive way to vibration management. The goal is to provide obvious guidelines for the construction of buildings and the development of urban areas to ensure that both the physical safety of structures and the health and rest of their resident are protected.

The results of research on the effects of vibration caused by transportation on the people who suffer this passive vibration are reported in many scientific papers [8,9,10,11]. In [8], the authors investigate the effects of vibrations caused by trains on people who passively perceive these vibrations. The basis for the current understanding of the effects of vibrations on people in buildings was set out in [9]. The analysis focused on the effect of building vibrations on the perceptibility of vibrations by people, no matter their origin. A more contemporary approach to the effects of vibration on humans in conjunction with the influence of noise can be found in [10]. In [11] not only noise but also vibrations, in this status, caused by rail traffic, were reported as stress-inducing factors. A modern way was also used in [12], where the spread of waves in the ground was also taken into account. These analyses cover different sides, including the strength of the vibrations, their frequency, and the effects of these vibrations on the well-being and health of the person. However, the available literature loss a global, comprehensive approach to this topic that would allow a complete understanding of the extent and particularity of the effect of traffic vibration on people in buildings.

In much research, detailed results on the effects of vibration on people are given without the appropriate context, making it difficult to draw general conclusions. Additionally, the origin of the vibrations is the most significant aspect for understanding the working mechanisms and their potential effects on humans that are often not considered. This is a great omission as the source of vibrations is fundamental to their characteristics.

2. Building and FEA Model

A spatial calculation model built according to the Finite Element Method (FEM) principles was adopted. Structural elements such as beams and columns were modeled with beam-type finite elements (two-node finite element with 6 degrees of freedom in a node), while surface elements such as walls and ceilings were modeled with shell elements (four-node or three-node finite element with 6 degrees of freedom in a node). Geometric dimensions were adopted by the provided design documentation. Partition walls in the calculation model were treated as a substitute surface load. ‘Figure 1’, and ‘Figure 2’ present a visualization of the calculation model of the building.

Concerning the entire structure, global damping was assumed with a critical damping fraction value of 5%, which corresponds to buildings with traditional masonry construction. The calculations included the dead weight together with service loads distributed evenly over the surface of horizontal partitions. The analysis used characteristic values of loads and cross-sectional forces. The calculations were performed using the direct integration method of the equations of motion. Kinematic loads were assumed in the form of recorded acceleration curves of vibrations applied at the base of the model (the contact point between the building and the ground) as uniform excitation.

The following parameters were assumed to characterize the materials used in the structure model:

- Concrete (Reinforced Concrete) C16/20 (B-20): Young's modulus E=29.0 GPa, Poisson's ratio ν=0.2, mass density ρ=2500 kg/m^3.
- Concrete (Reinforced Concrete) C25/30 (B-30): Young's modulus E=31.0 GPa, Poisson's ratio ν=0.2, mass density ρ=2500 kg/m^3.
- Porotherm block (f_b =15MPa, f_m =5MPa): Young's modulus E =3.9 GPa, Poisson's ratio ν =0.25, mass density ρ =1350 kg/m^3.
- Wood C-24: Young's modulus E =11.0 GPa, Poisson's ratio ν =0.3, mass density ρ =420 kg/m^3.

The following values of operational loads were assumed in the calculations:

- In residential premises 2.00 kN/m^2.
- In staircases 3.00 kN/m^2.

The model was verified based on tests of buildings of similar construction based on the frequency and mode of natural vibrations. The first three modes of vibrations together with the frequency values are presented in ‘Figure 4’.

Due to the structural layout and spans of monolithic ceilings in the building, the impact of vibrations on people was checked, particularly at point 1 specified in ‘Figure 3’.

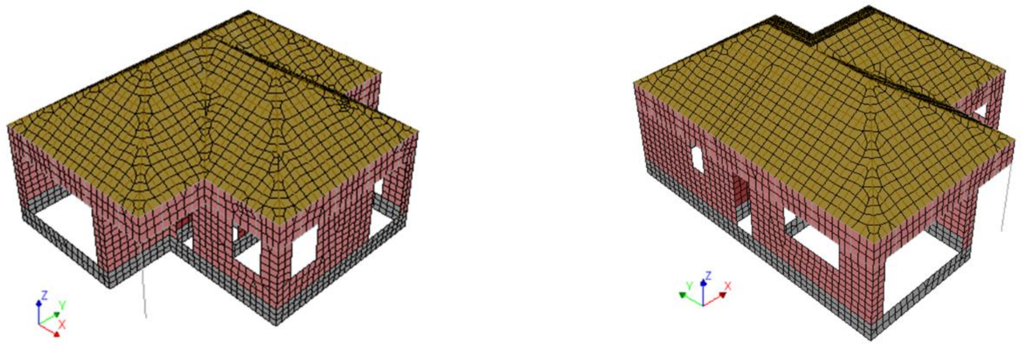


Fig. 1. FEM model.

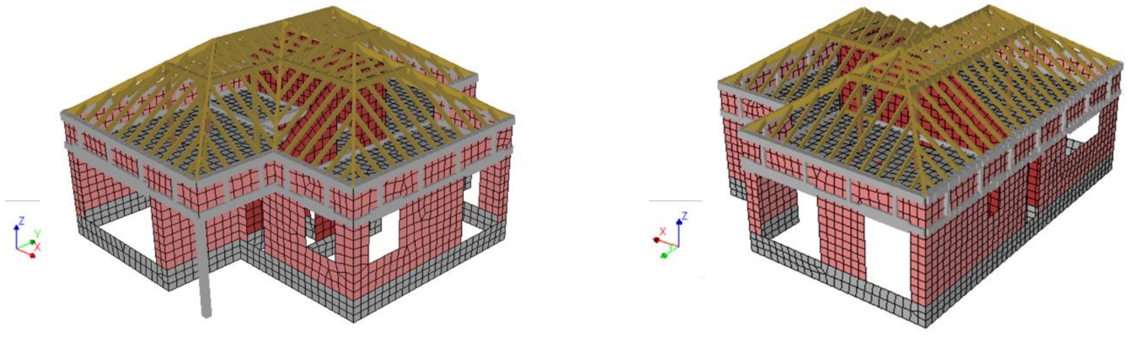


Fig. 2. FEM model – beam element layout.

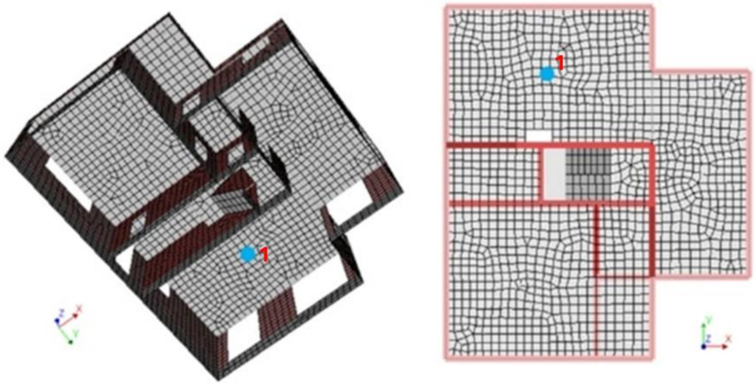
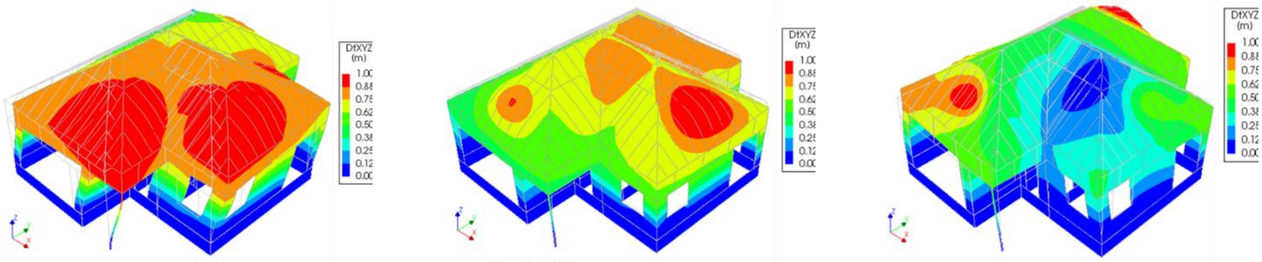


Fig. 3. FEM model – location of point 1 for analysis of the impact of vibrations on people.



f_1 =12.447 Hz f_2 =13.019 Hz f_3 =14.372 Hz

Fig. 4. The natural vibrations of the FEM model.

3. Railway Vibrations

The plot on which the facility is to be located is located near the railway line and is part of the pan-European E 30 route. Both passenger and freight trains run on the line. According to the current traffic schedule on the line in question, trains run both day and night.

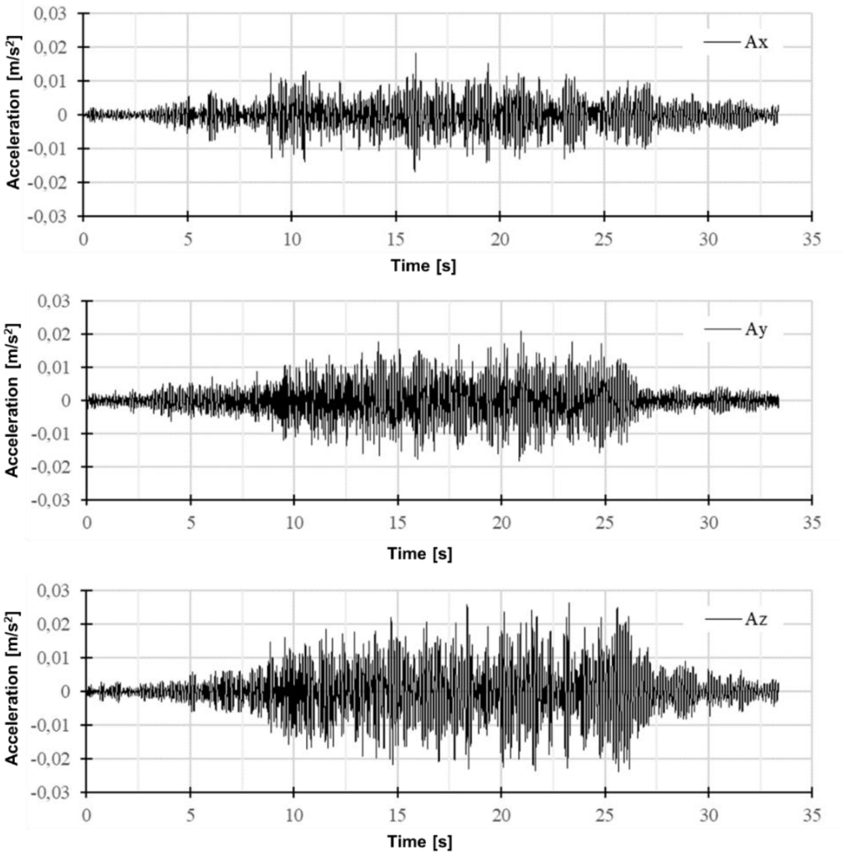


Fig. 5. Kinematic excitation from a freight train passing at a speed of 80 km/h, components x, y, z.

According to the current characteristics of the line, the permissible speed for trains depends on their type and is:

- Passenger trains: V_{max} = 160 km/h
- Freight trains: V_{max} = 120 km/h

Representative excitations from a railway line with similar characteristics and purpose were selected for the analysis. Excitations (a, b) were recorded on the foundation wall of a single-family building constructed using traditional technology with a similar building area and at around 30 m from the extreme track of the railway line.

Below, in ‘Figure 5’, and ‘Figure 6’ the recorded acceleration patterns of vibrations, which were assumed as kinematic excitations, are presented.

Due to the mixed passenger and freight traffic on the subject railway line, the following two scenarios were adopted for calculations:

a) Passage of a freight train (speed 80 km/h)

b) Passage of a passenger train (speed 160 km/h)

The trains belong to carriers who also provide transport on the subject railway line. These are trains and travel speeds typical for main lines.

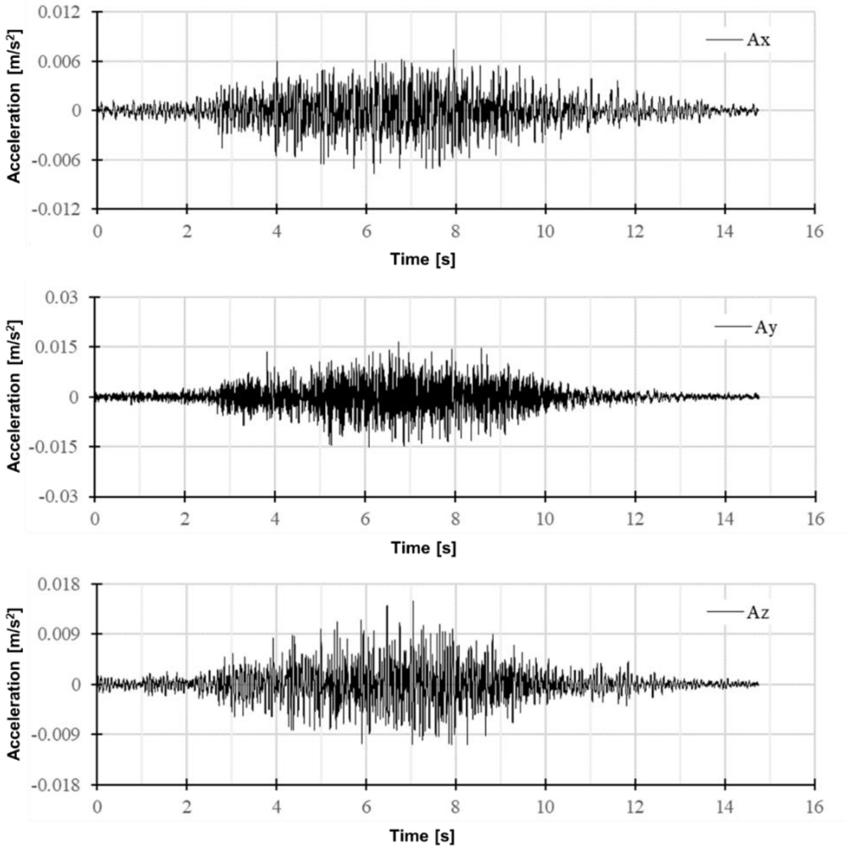


Fig. 6. Kinematic excitation from the passage of a Pendolino train at a speed of 160 km/h, components x, y, z.

4. FEA simulation & Results

The results of the analysis of the impact of vibrations on people are presented in the form of stepped graphs of the effective RMS (root mean square) values of vibration accelerations at the place of their reception by people, specified in third-octave frequency bands. The same drawings show lines corresponding to humans' threshold of vibration perception and the level permitted to ensure the required comfort for people staying in the room. The continuous lines correspond to vibrations in the direction parallel to the spine axis, and the dashed lines correspond to vibrations perpendicular to the spine axis.

In order from the lowest, the lines on the graphs represent:

- Threshold of vibration perception by humans.
- Comfort limit at night (threshold of vibration perception by humans with a multiplier of 1.4).
- Comfort limit during the day (threshold of vibration perception by humans with a multiplier of 4).

The tables also list the values of the vibration perception index WODL. This is the highest value of the ratio of effective values (RMS) of vibration acceleration determined in the individual 1/3 octave bands to the RMS acceleration value corresponding to the vibration perception limit for humans in the same frequency band, specifying the frequency for which the highest value was achieved.

The analyses carried out show that in the object in question, the vibration perception threshold for humans is exceeded, but the conditions for ensuring comfort for humans are met. In none of the cases considered were the comfort limit conditions for both day and night described in the PN-B-02171:2017-06 standard exceeded.

The maximum recorded values of the WODL indicator were determined for a freight train passing at a speed of 80 km/h (see Table 1, Table 2 and ‘Figure 7’), the WODL indicator is then 1.991 for daytime and 1.175 for nighttime.

The maximum recorded values of the WODL indicator were determined for a passenger train passing at a speed of 160 km/h (see Table 1, Table 2 and ‘Figure 8’), the WODL indicator is then 3.145 for daytime and 1.099 for nighttime.

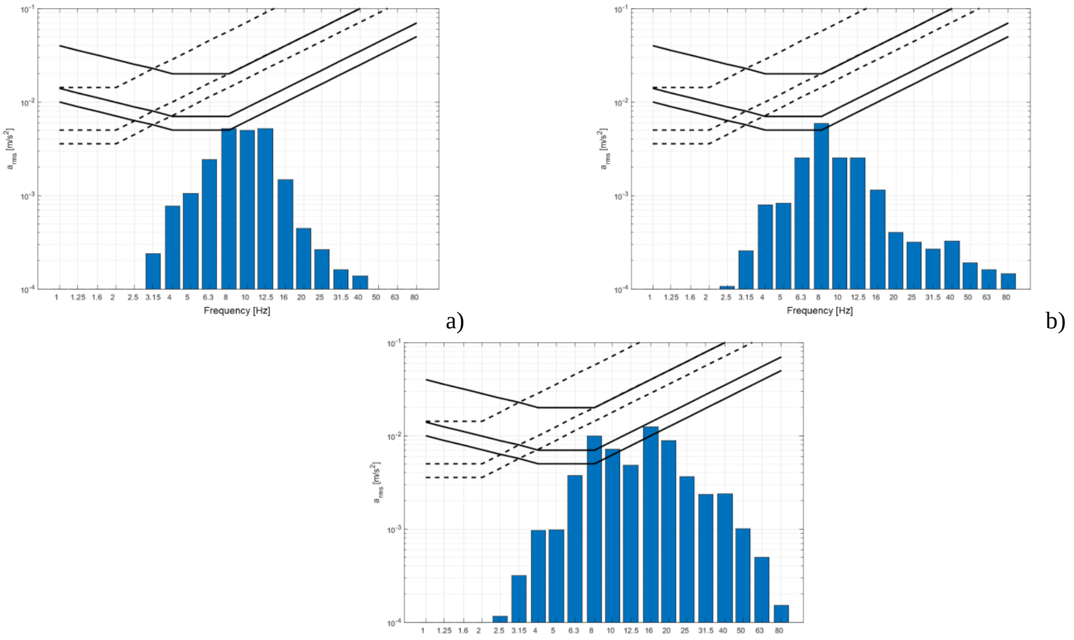
It should be recognized that the comfort conditions according to the PN-B-02171:2017-06 standard for the subject building located on the railway line are met.

Tab. 1. WODL indicator – measurement point 1 – daytime.

Time of occurrence	**Day (WODL < 4.0)**					
Vibration direction	**X**		**Y**		**Z**	
	F [HZ]	**[-]**	**F [HZ]**	**[-]**	**F [HZ]**	**[-]**
Freight 80 km/h	**8**	**0.361**	**8**	**0.411**	**8**	**1.991**
Pendolino 160 km/h	**12.5**	**0.216**	**12.5**	**0.147**	**16**	**3.145**

Tab. 2. WODL indicator – measurement point 1 – nighttime.

Time of occurrence	**Night (WODL < 1.4)**					
Vibration direction	**X**		**Y**		**Z**	
	F [HZ]	**[-]**	**F [HZ]**	**[-]**	**F [HZ]**	**[-]**
Freight 80 km/h	**8**	**0.361**	**8**	**1.175**	**8**	**0.696**
Pendolino 160 km/h	**12.5**	**0.216**	**12.5**	**0.423**	**16**	**1.099**

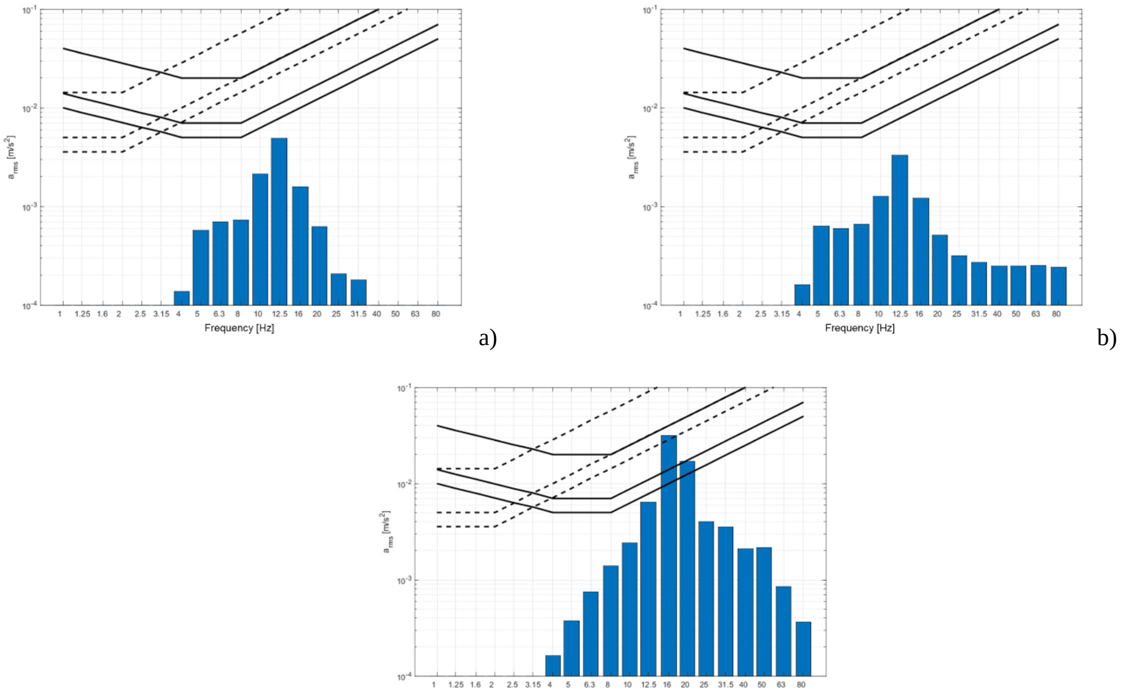


a)

b)

c)

Fig. 7. The result of the assessment of the impact of vibrations on people caused by a freight train passing by at a speed of 80 km/h at point 1 of the FEM model – components X, Y, Z, respectively



a)

b)

c)

Fig. 8. The result of the assessment of the impact of vibrations on people caused by the passage of a Pendolino passenger train at a speed of 160 km/h at point 1 of the FEM model – components X, Y, Z, respectively

5. Conclusion

The main objective of the work was to determine the impact of vibrations on the designed single-family masonry building. The source of vibrations in this case will be the passage of railway trains on the nearby railway line, which is part of the pan-European route E 30. Both passenger and freight trains run on the line, both during the day and at night.

Calculations were carried out on a spatial FEM model. The kinematic excitations were assumed to be the acceleration courses of vibrations recorded on the foundation wall of a single-family masonry building.

As part of the analyses, calculations were carried out in the time domain regarding the impact of vibrations on the structure of the building and people staying in it, in possible calculation scenarios.

As a result of the calculations and analyses of the data obtained by the PN-B-02170:2016-12 and PN-B-02171:2017-06 standards, two main conclusions can be drawn from the calculations:

- The impact of vibrations on the building structure from the nearby railway line is small and will not cause any negative effects.
- The vibration impact on people staying in the building of the question is perceived yet does not go beyond the permissible level designated in the PN-B-02171:2017-06 standard by the Polish.

The calculations and analyses carried out, to increase the comfort of people staying in the building below the vibration perception threshold, indicate the need to use the class of structural concrete C25/30 (B30), increase the thickness of the slab to 22 cm and use vibration insulating mats at the foundation level. The adoption of the above modifications must be taken into account by the designer in the static calculations.

During the implementation of the investment, the technological regime and principles of proper construction art must be observed during the construction of the facility, in particular:

- Building materials should be certified and approved for use in the country.
- The layout of floor layers provided for in the construction design must be maintained.
- It is necessary to ensure that the reinforcement works are properly carried out by the construction design. especially, this applies to the diameters and spacing of the reinforcement inserts as well as their correct anchoring and connection through the overlap.
- The concrete mix must be properly maintained. This applies especially to the ceiling slab and load-bearing beams. The ceiling must not be stripped too early when the concrete has not yet achieved the appropriate strength in the early phase.

Acknowledgments

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