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Application Of Noise Reduction Equipment In The Modernization Of The EU Railway Development

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ABSTRACT

Our work presents various noise reduction measures, which, with the account of the relief of the country and the location of townships, should be designed in the modernization of railway lines. Here, beside the already known noise reduction measures, like noise screens; embankments and various constructions, the types of noise screens, intended for low-frequency noise reduction, which were studied by the authors [1, 2, 3] are presented in the work. Attention in the work is devoted to the impact of infrasound on the people living near the railway. Here, the propagation of vibrations through the ground to the residential buildings is also researched.
With this aim in view, the natural trials for clarification of vibration propagation process from the railway lines (railings) to the residential building were performed.
It was established by research that low-frequency vibrations (in dependence on the ground composition) propagate quite far (up to 200 m and more) and have an effect on the foundation of buildings, which, in their turn, generate the wall vibrations in the building. Those wall vibrations excite the inaudible sounds (infrasound) inside the premises and have an unpleasant impact on the population.
On the basis of those data, measures were foreseen that reduced the amplitudes of vibration propagating in the ground and thus the impact of unpleasant sounds on the residents.
The results obtained will be used in the recommendations when designing noise reduction measures and expanding a railway network in the Baltic countries.

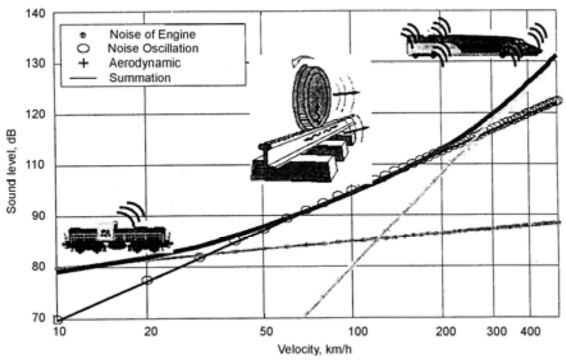
INTRODUCTION

In geographical terms the territory of Lithuania and other Baltic states is convenient for transit cargo transportations in the East–West and South–North directions, therefore after entering the European Union (EU), the necessity arose for Lithuania and other Baltic states – Latvia and Estonia to integrate in the European railway system, approximating the railway infrastructure to the level of the European Union countries. For that purpose, a strategic project of North–South railway has been developed Tallinn in Estonia - via Latvia and Lithuania - with Warsaw in Poland. Despite the fact that Rail Baltica is one of the TEN-T priority projects, it has become clear that very little specific planning and analysis has been made for the project in the countries.
Our analysis performed allows one to state that Lithuanian Railway lines are unqualitative and due to such and other reasons a noise level near the passing railway lines is rather high and reaches 110 and more dB(A) [1, 2].
Railway lines, along which various types of trains are moving, have no protection technical measures against the increased impact of noise (of type of screens), etc.
Therefore the environmental problems, including those of noise impact, have been foreseen in a strategic study.
A strategic study of the Rail Baltica railways has been conducted in the period November 2005 - December 2006 on the request of the European Commission, Directorate-General Regional Policy. The objective of the pre-feasibility study has been to assess strategically the overall need and potential for developing Rail Baltica and to provide recommendations for project implementation of the most suitable development option in terms of alignment, technical standards and organisation.
An expert commission, formed by the Railway Cooperation Organization, developed and approved a number of documents, dealing with the train noise measurement, the evaluation of impact on the environment and recommendations for its reduction.
The main idea behind Rail Baltica is to develop high-quality connections for passenger and freight transport between the Baltic States and Poland, as well as between the Baltic States and other EU countries through the hub Warsaw. Improved rail lines will result in more efficient land-bound connections between the Baltic and the Nordic countries (particularly Finland) and in the long run
potentially further to Central Asia. Improved rail links will benefit the environment, contribute to alleviate congestion on the European road network, increase the accessibility of the Baltic States and potentially improve conditions for accelerated regional development in the countries involved.
For the successful implementation of the project, currently, it is necessary to investigate the noise caused by the trains moving along the railways, to identify the reasons of its formation and to foresee the main measures for reduction of noise propagation. It is understandable that in order to make a step forward, we had to analyze the works already performed by the acoustical scientists working according to the given themes and to take the

noise-reduction solutions, complying with the national interests and the existing conditions.

PROBLEM AND ITS SOLUTION

Noise in the territory near the main road, propagated into the surrounding space, during the train movement, alongside the noise, which is being formed inside the railway rolling stock, is the most important constituent of the noise of trains. Noise in the territory near the main road depends on different factors, such as the interaction of the rolling stock and the line, vibrations of constructions, speed of the train movement, length of the stock, turbulence of air flows, aerodynamic forces at high speeds (i.e. > 250 km/h), etc. [3 - 9].



Figures 1. Dependence of noise generated by the train elements on the train movement speed

In figure 1, it see noise characteristics of various means of transport, their analysis and effects on the environment.
Here an example is given of one vehicle with several types of noise sources and the principles of their operation (see Fig. 1). In the Figure, the dependence of the cumulative noise from separate sources on the speed of movement is shown.
From diagrams, presented in Fig. 1, it is seen that separate transport mechanisms (sources) and their technological factor in the environment generate the noise of different intensity, the force whereof depends on the speed produced by means of transport. The given example shows that the general noise by one means of transport is the total of several noise sources with different noise characteristics. In the Figure we see the contact of the wheel of the carriage, moving on the rails, with a rail. Here we can notice that the roughness (wearing) of the wheel and rail surfaces may induce the additional noise to the general background of the train.
Research of the Danish scientists [10, 11] shows that the combined roughness determines the generated noise level. This means that both the wheel surface and the rail surface need to be smooth, if a significant noise reduction shall be obtained. This key statement is illustrated in Fig. 2. The well-known methods to remove surface roughness and defects are reprafiling for wheels and rail grinding fore track. Today, the periodical removal of roughness is the most used method for roughness reduction. The tools are commercially available, and roughness is now predominantly an economic and not a technical problem. Wheels and rails are, however, also reprofiled or ground for other reasons, which primarily is safety.
More and more rail operators, however, also consider how roughness growth can be prevented. This means that low-noise rail vehicles remain quiet.
The most important processes to avoid are gliding and wear. During gliding a local part of the wheel or rail becomes so warm that the steel structure is changed irreversibly [4]. For tread braked wheels using conventional cast iron brake blocks the excessive heating is not local but distributed over the entire tread of the wheel.
During gliding, perlitic steel is typically converted to martensitic steel, which is much harder than perlite. This – as an example – takes place during the creation of a wheel flat. The conversion to martensite will create an inhomogeneous steel structure, which reduces the smoothness of the surface. These changes create cracks resulting in surface imperfections and finally material fallout.
Alongside the air noise, which is radiated in the surrounding space, structural noise and vibrations arise and they are excited by dynamic forces at the point of the contact of the wheel and the rail at the movement [12, 13]. Those vibrations are propagating along the upper structure of the line and the bearing constructions, passing over the adjacent to the neighbouring buildings. They usually are perceived by man as low-frequency mechanical vibrations. People who live or work close to the main road complain of those negative phenomena.
The authors of this work faced the said problem already earlier when they received an inquiry to investigate the analogous complaints from the inhabitants who were under the effect of low-frequency vibrations, excited by infrasound from the closely operating plant. In that plant, with the help of a vibromachine, construction blocks were manufactured [14].
Therefore this issue will be broader investigated in our work. Here it is also necessary to note such cases that when the railroad line passes through the section with slopes or along the elevated lines, the air noise prevails over the structural one.
It was also noted the increased noise level when the train wagons are directed to loading-unloading station.
The noise in the marshalling yard and noise in the railway transport production enterprises may be the main in the territory close to the main road in the region of the residential blocks, adjacent to those objects. The main sources of noise are rail tractors and noise from the collision of wagons. The noise level usually in this case exceeds by 20-30 dBA and more the level of the surrounding background. At a distance 30 m. from the axis of the lines, the level of the noise from the collision of wagons makes 95–100 dBA.
People, living near the urban area, close to the railway lines, which are located under the viaducts and other road facilities, complain that the generated vibrations from the passing train are felt in the residential houses.
At present as regards the transport harmful impact on the environment, it is related not only with the radiating, audible sound (noise), but also with the vibrations and their excited infrasound. Therefore in the project "Rail Baltica" it is foreseen together with the noise screens to implement the measures for reduction of vibrations as well.
Many railway lines were built long ago and not taking into account the noise impact on the environmental territory. Townships and villages, near which the fast railway networks are laid, experiences harm (noise, vibrations and infrasound). For solving this problem the joint efforts of the state, local administration and railway companies are needed. Planning new railway lines according to the project "Rail Baltica", the optimum railway line designing is needed, taking into account a distance from the road to the closest building and the land excavation. To reach the noise level normative values, for reduction of the effect, it is necessary to perform the additional research works and evaluation of the impact of vibrations on the environment before the beginning of the constructions, the predicted railway noise and vibrations impact and the necessary measures of their reduction at the stage of designing.
Modern technology makes it possible to substantially reduce structural noise and vibrations, related to the construction of the line and structures. If a distance from the line to the buildings, subject to the action of the factors under study, is less than 10-15 m, the realization of the protective measures may require high funds.
In this work, we will show how the excited low-frequency vibrations, propagating in the ground, reach the residential buildings and how to get protected from such vibrations.
The last investigations into noise sources in the railways show that vibrations which propagate into the environment also may be the object of research, e.g. vibrations, which are excited in the constructions and the ground by the train passing by.
Propagation of vibrations though the ground has not been investigated so far, since in this process many various factors,

which have an impact on the distribution of vibrations in the grounds, participate. Therefore in this work the major attention will be focused on the properties of the propagation of vibrations and their insulation (the harmful impact on the environment).

VIBRATIONS EMITTED BY THE SOURCE AND THEIR IMPACT ON ENVIRONMENT

Advanced technologies and equipment penetrated even remote outskirts of nature. Vibration and noise can be emitted from different sources, such as power grid unit substations, compressor houses, vibration equipment used in production of construction materials and other mechanisms of advanced technology.

Owing to high intensity of dynamic activity of major volumes in the labor process the vibrations emitted to the environment invoke not only vibrations that radiate through structures and soil but also produce noise. Vibrations of low frequency and high intensity radiate through soil and building structures and in that environment invoke infrasonic waves. Infrasonic waves are as harmful as audible sound waves, i.e. noise. Infrasonic waves must be investigated more closely and standards of their allowed intensity must be defined.

As an example, some operated air compressors emit vibrations ranging from 2 to 12 Hz decibels and invoke general sound pressure level by 110 dB and more. Here sound pressure levels reach 73 – 75 dB (A). At a distance of 100 – 150 meters from residential buildings sound pressure levels as a rule range from 80 to 100 dB. Motor vehicles in operation emit similar vibrations.

Scientists investigating the effect of infrasonic waves on human health have established that sound pressure level up to 90 dB does not lead to complaints on the side of residents, however laboratory investigations revealed the following facts.

Investigation was carried out in the infrasonic field of equations 110, 100 and 90 dB at frequencies 4, 6, 8, 12 and 16 Hz. Infrasound at frequencies of 6 and 12 Hz with the intensity of 110 dB at 15-minute exposition causes statistically valid changes on the part of the central nervous and cardiovascular system; the short-term effect of infrasound at frequencies of 4, 8 and 16 Hz impacted the central nervous system of those under study, causing the prolongation of the latent period of reflecting reactions on the sound and disorder of power relations, which were also preserved in the rehabilitation period. Those under subjective observation noted some pressure in the sinciput area and the inhibited condition (were drowsy). Change in some other indicators totally in the group was not trustworthy.

Thus, a level of 110 dB even at the short-term exposition should be considered to be as acting.

Infrasound at a level of 100 dB also had an effect on the central nervous system, however, some difference was observed in its response reaction in dependence on the frequency: more expressed at a frequency of 16 Hz and less expressed at a frequency of 4 Hz. Other physiological indicators were without the substantial changes. Consequently, the level of 100 dB may be considered as a threshold one.

Further we shall study how vibrations from our selected object of exploration, i.e. from a vibromachine for manufacture of construction blocks in the city of Šiauliai are propagating.

Vibrations of the foundations of a vibromachine excite the vibrations of the ground massive on which it is erected. Since the ground has the properties of the elastic medium, the vibrations in the form of waves propagate to all sides from the foundations to considerable distances, reaching 500–1000 m. Buildings and structures, located in the zone of propagation of those waves, are subject to vibrations. Vibrations may be dangerous, having an effect on the durability of buildings and structures, or harmfully affecting people and equipment. In these cases it is necessary to take special measures for prevention of impermissible vibrations and for elimination of vibrations of the already existing objects. For correct selection of such measures it is necessary to have an understanding about the character of impact of those waves on the objects, and the forms and parameters of vibrations of buildings and structures.

As a calculation model of the phenomenon of elastic waves in the ground, the elastic isotropic half-space, into which the vibrating mechanism with the flat foundation of rectangular form was impressed, was taken. Two types of waves propagate from the vibrating mechanism independently of one another: waves, in the presence of which the ground experiences only a relative change in the volume, or waves of compression and extension, and waves, in the presence of which the ground particles just experience the relative displacement, or shear waves. The former are called longitudinal, since the ground particles during the propagation of such waves are displaced in parallel to the direction of wave propagation (along the radial straight line from the source). The latter are called transversal, since the displacement of the ground occurs perpendicularly to the propagation of a wave.

Relationship between velocities c_1 and c_2 of the propagation of the former and latter waves is determined by an expression:

$$\frac{c_1}{c_2} = \sqrt{\frac{2(1-\mu)}{1-2\mu}},$$

here μ – Poisson coefficient

In all cases the relation $c_1 / c_2 > 1$, consequently, the longitudinal waves are propagated with the higher velocity than the transversal waves. Numerical values of the velocities of longitudinal and transversal waves in different grounds [15] are given in the table.

Ground	Wave propagation velocity, m/sec	
	c_1	c_2
Humid clay	1500	150
Loess of natural humidity	800	260
Solid gravel-sandy ground	480	250
Sand:		
Finely granulated	300	110
Medium granulated	550	160
Medium-sized gravel	760	180

In addition to longitudinal and transversal waves, one more type of waves appears on the surface of the ground – surface waves, penetrating the ground not deeply. The foundations of the vibrating mechanism under study are the sources of wave excitation in the ground, and the foundations of buildings and structures, the receivers of waves, are situated close to the surface of the ground. Therefore surface waves are of special interest for us. Longitudinal and transversal waves are propagating in three dimensions, whereas surface waves only in two dimensions, and already at a comparatively small distance from the source they prevail over longitudinal and transversal waves, since the relative energy of surface waves diminishes in proportion to the distance from the source, and that of longitudinal and transversal waves in proportion to the square of the distance.

Velocity c_3 of surface wave propagation is somewhat lower than the velocity of propagation of transversal waves c_2. Thus, at $\mu = 0.25 \div 0.5$; $c_3 = (0.92 \div 0.95)\, c_2$. The frequency of the vibrations of the ground, propagating from the foundations of the operating machine by surface waves is equal to the frequency of the vibrations of the foundations.

Length of the propagating wave $L = c_3 / f$. Length of surface waves, propagating from the foundations, at the process of operation in the different media of the ground is within the range of 17 to 63 m.

Amplitudes of vertical and horizontal constituents of the ground vibrations decrease with the increase of the depth, but at small depths (within the limits 0.2–0.5 of the wave length) they change comparatively insignificantly. This circumstance is of practical importance. Since the amplitudes of the ground vibrations from the surface waves propagating from the foundations at a depth of 8–30 m do not change practically, there is no sense for the purpose of decreasing the amplitudes of vibrations to increase the depth of laying of the foundations of buildings and structures – receivers of waves. Nor there is necessity to lay the foundations at the depth lower than the foundations of the closest structures (walls, columns).

Amplitudes of the ground vibrations decrease depending on the distance of the source of vibrations. Vibrations are less intensive in the direct approximation to the source of attenuation of vibrations than at large distances from the source. Therefore in practical computations, the amplitudes of the ground vibrations close to the foundation in the circle of radius r_o, equaling the greatest value of the base of the foundation, are taken as constant and equal amplitudes of vibrations of the foundation, and at great distances are determined by a formula

$$A_r = A_0 \sqrt{\frac{r_0}{r}} \cdot e^{-\alpha(r - r_0)}, \qquad (1)$$

here A_r; A_0 are amplitudes of the ground vibrations at a distance from the source; α is the rate of attenuation, the value of which fluctuates for different grounds from 0.03 to 0.1 m^{-1}. Under other similar conditions the frozen grounds have lower values of the rate of attenuation α. Consequently, the waves of the vibrating mechanism in the winter propagate at higher distances than in the summer.

This theoretical statement was confirmed by our experiments performed in the specific object.

INVESTIGATION OF VIBRATION PROPAGATION THROUGH THE GROUND IN TERMS OF THEIR REDUCTION, ANALYSIS AND MEASURES

In order to investigate the impact of vibrations on the environment, it is necessary to study the parameters of vibrations that propagate through the ground in the environment under study. This information is also necessary for investigating the emergence of vibrations in the residential premises and for foreseeing measures for their reduction.

Vibration values are measured using the vibration measuring systems, which consist of a sensor, amplifier, filters and indication device. Vibrations were measured in the intervals of standard octaves, by means of the vibration meter 2511.

Experimental measurements of vibrations were carried out in the enterprise's premises and territory, see Fig. 2

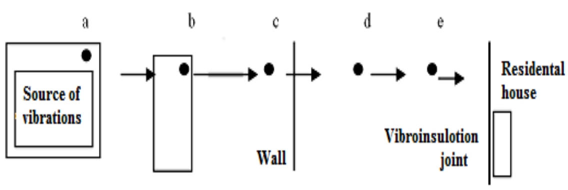


Figure 2. Layout of measurement points in the room and the enterprise's territory.
a – vibromachine base, b – operator's booth,
c – inside near the external wall,
d – outside,
e – at a distance of 100 m from the vibration source

Measurement results are provided in diagrams (Figures 3a, 3b, 3c, 3d, 3e).

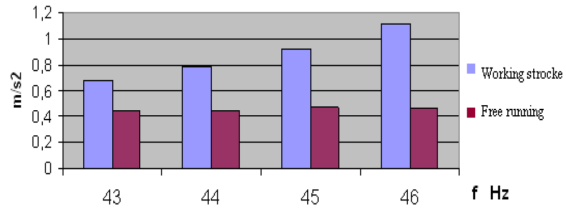


Figure 3a. Vibration results in the shop on the equipment (machine) base m/s^2

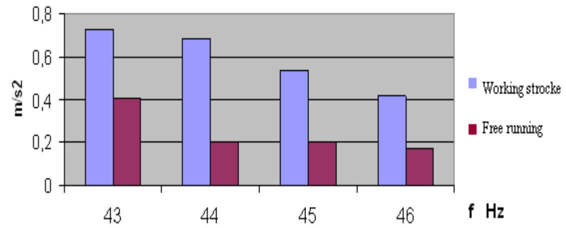


Figure 3b. Operator's work booth in the shop at the main control panel on the floor m/s^2

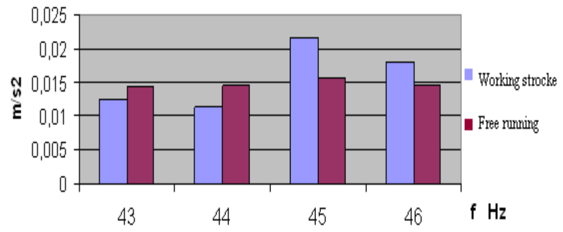


Figure 3c. In the shop near the internal wall on the floor m/s^2

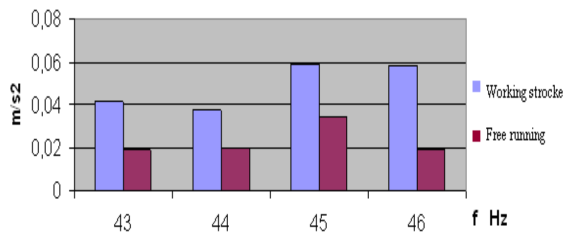


Figure 3d. In the enterprise's territory on the ground surface at a distance of 50 m m/s^2

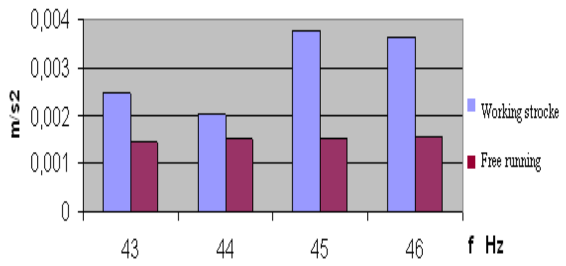


Figure 3e. In the territory of the enterprise's shop, at a distance of 100 m on the ground surface m/s^2

The assessment of the process of dispersal vibration into the environment will be presented in the amplitude weakening vibrations diagram.

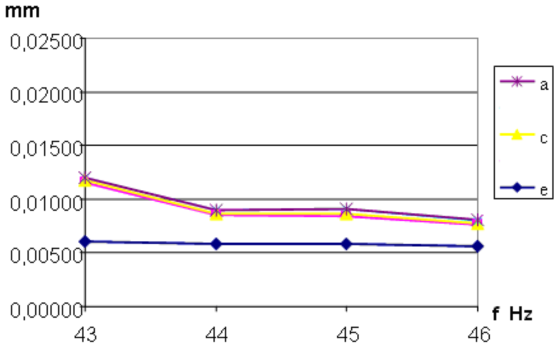


Figure 4. Amplitudes of vibrations during the free running of work

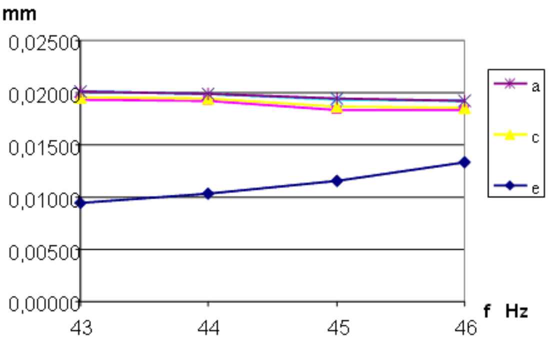


Figure 5. Amplitudes of vibrations during work

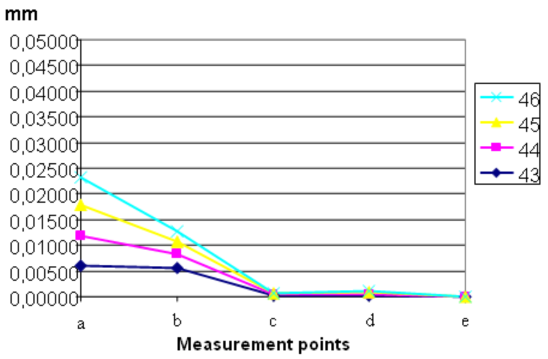


Figure 6. Amplitudes of vibrations further from the source of vibrations during the free running of work

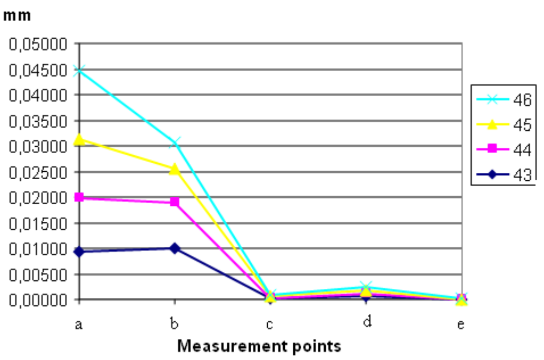


Figure 7. Amplitudes of vibrations further from the source of vibrations during work

Graphics (Fig.4,5,6 and 7) show that vibrations emitting along the ground surface abruptly decreases at the outside of premises, though vibrations emitting along deep layers of the ground reach the foundations of dwelling buildings. It is possible to confirm this in reference to theoretical arguments.

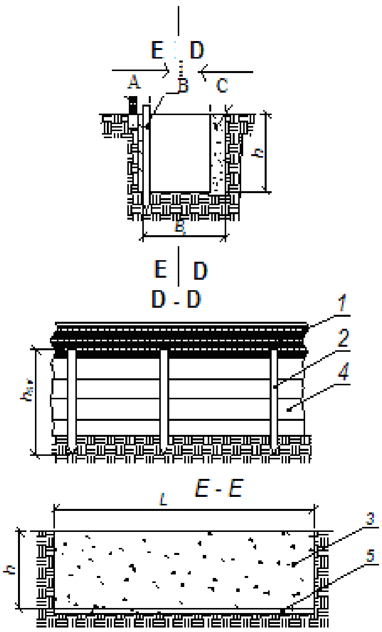
In diagrams, shown in Fig. 3a, 3b, 3c, 3d, 3e, the layout of the acceleration values of vibrations by frequency at an interval of 1 Hz from 43 to 46 Hz may be seen. Here in different columns it is possible to distinguish two values of the vibrations at the same frequencies during the different performance of the technological process. It is seen that during the operation process, the value of the parameter of vibrations is considerably higher. From here, a conclusion may be made that the value of vibrations generated during the technological process is fluctuating during one cycle. Further away from the source of vibration, the value of parameters of the generated vibration reduces, e.g., the measured acceleration of vibrations on the foundation and outside the building (on the ground at a distance of 100 m). Acceleration of vibrations reduces from 0.5 to 1.0 m/s^2, and 120 m away vibration reduces to the values of 0.004 m/s^2. However, such values when they reach the foundations of the residential buildings transmit them to the walls and turn into the sound (infrasound). After the performance of measurements in the premises (bedroom) of the residential house, vibrations of the frequency of 10-12 Hz and the sound (infrasound) of the corresponding frequency were registered.

THE WAYS FOR REDUCTION OF VIBRATIONS

Many methods and ways of reduction of the intensity of the parameters of vibrations exist. They are applied taking into consideration the type of the source of vibrations, its specifications and destination. For reduction of the intensity of the parameters of the source of vibrations under exploration, it is possible to apply the following more important methods from those of numerously existing. Namely, reduction of vibrations at the source of their onset, on the way of propagation, and increasing the distance from the source and the object protected from the impact of vibrations. Let us touch in brief the essence of these methods and the opportunities for their application in the case of our exploration

However, it is necessary to state that the above indicated and still not indicated ways for reduction of vibrations by the pointed out method are not always and not everywhere applicable. In the case of our exploration, a vibromachine must excite the vibrations of the required intensity of the working part of the mechanism, which are necessary for the fulfilment of the preset working process. Therefore in this case attention shall be concentrated on the bearing part, where the vibrating mechanism is fixed by way of damping and insulation.

For reduction of the transmission of vibrations through the ground, a vibroinsulation joint was installed (See Fig. 8), the channel of which was filled with keramzit granules (see Fig. 9). After the implementation of that measure, no vibrations and outside sound signs were registered inside the residential house.



Explication:
1. The brick wall at the house
2. Poles for the support of partitions and for the future screen
3. Concrete - ferro - concrete barrier
4. Polymer or other plate material of the corresponding strength for sustainability of the ground
5. Barrier bottom
A, E, C, h and L dimension are given in the calculation

Figure 8. Vibroinsulation Joint

Figure 9. A vibroinsulation joint in the enterprise's territory between the source of vibration and the residential houses. It is 4.5 m deep and about 100 m long. A vibroinsulation joint is filled with keramzit granules.

CONCLUSIONS

1. During an analysis of railway moving transport vibrations and noise excitation sources, it was determined that with the train moving, due to various reasons, the excited vibrations through the metal railing and its fastening equipment are transferred to the ground.

2. The analytical investigation of vibration propagation through the ground, conducted in the work, showed that low-frequency vibrations propagate quite far, and this is one of the stronger reasons for impacting the inhabitants, living near the railway lines, and their making feel anxious.

3. Investigation of vibrations propagating to the environment showed that surface waves of vibrations propagate far with a certain gradual attenuation, but depending on the power of the source of vibrations they remain harmful and able to excite the low-frequency vibrations of the structures of buildings and the corresponding sound.

4. The measure, recommended in the work, for insulation of transmission of vibrations, reduced the amplitude of vibrations propagating through the ground to the impact, which was not harmful to the environment and people.

5. On the basis of theoretical and experimental investigations, it is possible to state that with the railway lines passing close to the residential houses it is necessary to install analogous vibroinsulation joints.

6. While implementing the "Rail Baltica" project, in designing the screens for noise reduction, it is necessary to foresee the places where it would be necessary to implement our recommended measures for insulation of vibrations, adjusting their installation together with the foundations of noise screens.

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